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HIGGS AND NEW PHYSICS SEARCHES WITH ATLAS*

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This paper covers the results of a search for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at the LHC. The datasets used correspond to integrated luminosities of approximately 5.0 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.5 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4l$, $H \to \gamma\gamma$ and $H \to WW \to l\nu l\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)} \to 4l$, $H \to \gamma\gamma$, $H \to WW \to l\nu l\nu$, $H \to b\bar{b}$ and $H \to \tau\tau$ in the 7 TeV data and results from improved analyses of the channels $H \to ZZ^{(*)} \to 4l$, $H \to \gamma\gamma$ in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of $126.0 \pm 0.4(\mathrm{stat}) \pm 0.4(\mathrm{sys})$ GeV is presented. This observation, which has a significance of 5.9 standard deviations is compatible with the production and decay of the Standard Model Higgs boson. Searches for signs of physic beyond the Standard Model, in a large variety of signatures are also presented with any experimental evidence.

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1. Introduction

The Standard Model (SM) of particle physics has been tested by many experiments and has been shown to successfully describe high energy particle interactions. However, the mechanism that breaks electroweak symmetry in the SM has not been verified experimentally. The LHC [1] experiments, ATLAS and CMS, have reported the observation of a new particle in the search for the Higgs boson. This paper covers the results reported in [2] and the absence of experimental evidence of signatures involving events with abnormal production of missing transverse momentum, jets, leptons and some other results on model with high invariant mass with two leptons and $t\bar{t}$ resonance.

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2. ATLAS detector

The ATLAS detector [3] is a multi-purpose particle physics detector with approximately forward–backward symmetric cylindrical geometry. The inner tracking detector (ID) with a pseudo-rapidity coverage of $|\eta| < 2.5$ consists of a silicon pixel detector, a silicon micro-strip detector, and a transition radiation tracker. The ID is surrounded by a thin superconducting solenoid providing a 2 Tesla axial magnetic field. A high-granularity lead/liquid-argon sampling calorimeter (LAr) measures the energy and the position of electromagnetic showers within $|\eta| < 3.2$. LAr sampling calorimeters are also used to measure hadronic showers in the end-cap ($1.5 < |\eta| < 3.2$) and forward ($3.1 < |\eta| < 4.9$) regions, while an iron/scintillator tile calorimeter measures hadronic showers in the central region ($|\eta| < 1.7$). The muon spectrometer (MS) surrounds the calorimeters and consists of three large superconducting air-core toroid magnets (0.5 Tesla in average), each with eight coils, a system of precision tracking chambers ($|\eta| < 2.7$), and fast tracking chambers for triggering ($|\eta| < 2.4$). A three-level trigger system selects events to be recorded for offline analysis.

Despite the high pile-up level, interactions per crossing up to 40, the detector performances are excellent. For instance, the relative energy scale is below one per mil as function of the interaction per crossing and also as function of time over one year.

3. SUSY

Supersymmetry (SUSY) [4] is one of the best motivated theories for physics beyond the Standard Model (SM) since it provides a solution to most of its shortcomings. The ATLAS experiment has developed a large and coherent SUSY search strategy. It is not possible to describe all results in this paper, only two examples are presented. The first example is a simplified MSSM model with only gluinos, first and second generation squarks and a massless LSP (χ^0) is considered. Squarks and gluinos are forced to decay with 100% branching ratio via $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$ and $\tilde{q} \to q\tilde{\chi}_1^0$. The mass limits are close to or above 1 TeV for first and second generation squarks and gluinos, see figure 1, left. In the case of equal squark and gluino masses, a mass limit of 1.5 TeV can be reached with $\sqrt{s} = 8$ TeV data [5]. The second example is the search for direct top squark (stop) production, five exclusive analyses [6–10] are designed to probe the stop decay channels. They can be divided into lepton veto analyses sensitive to high stop masses with massless LSPs and leptonic analyses which cover more compressed scenarii. In all cases, the dominant background comes from the top quark pair production and different discriminant variables are chosen in each analysis to maximize the sensitivity. The final status of the search at $\sqrt{s} = 7$ TeV is shown in figure 1, right. Stop masses below 500 GeV are excluded for LSP masses below 80 GeV, except for a small mass window around the top mass.

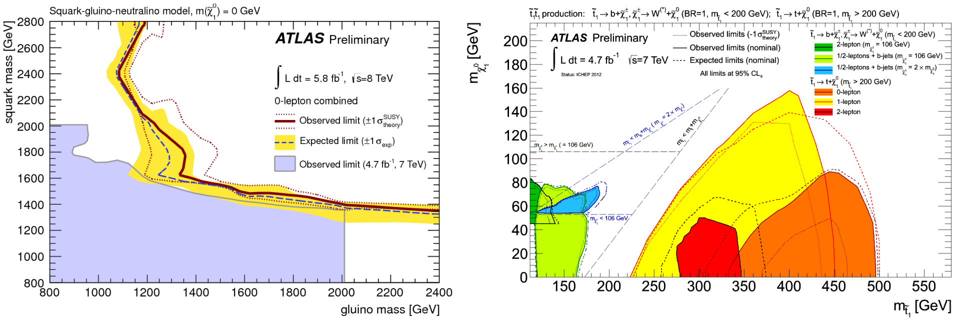

Fig. 1. Left: Simplified MSSM scenario with only strong production of gluinos and first- and second-generation squarks, with direct decays to jets and massless neutralinos [5]. Right: Final status of direct stop searches at $\sqrt{s} = 7$ TeV [6–10].

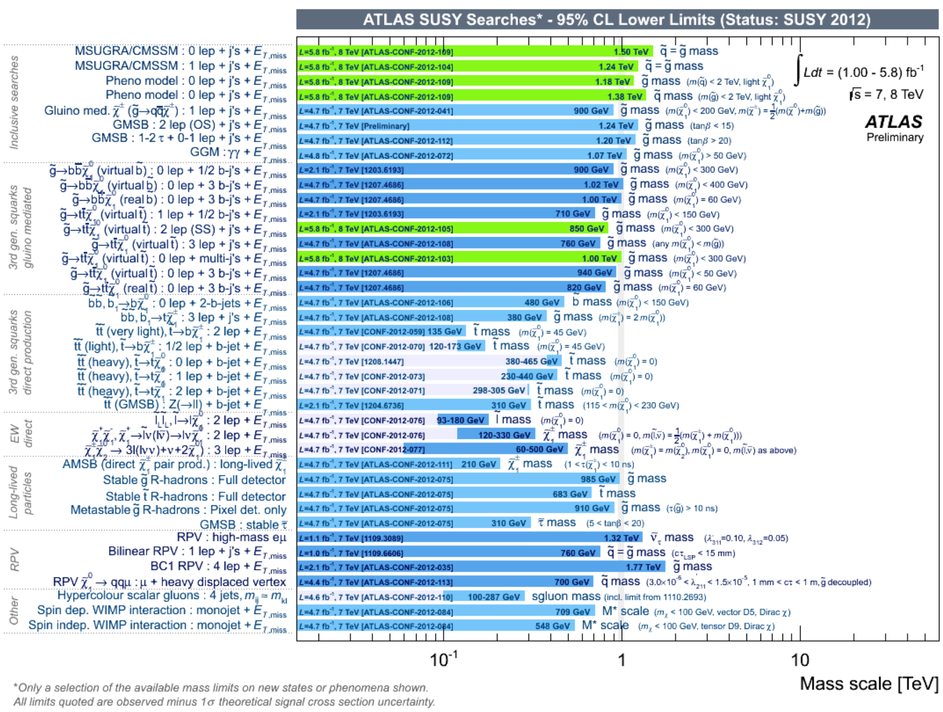

Fig. 2. Overall Status of ATLAS SUSY search results [11].

More than 50 analyses have been completed at $\sqrt{s} = 7$ TeV and the first results start to appear for 8 TeV data. No sign of New Physics has been observed, therefore, exclusion limits have been on many signatures, see figure 2.

4. Exotics

Searches for physics beyond the Standard Model can be based on specific theoretical models or, more generically, on different detector signatures *i.e.* analyses of dilepton, diphoton, dijet and diboson final states. It is not possible to describe all results in this paper, only two examples are presented. First, the dilepton analysis is performed in the dielectron and dimuon channels [12]. The main background of the analysis is the SM Drell–Yan production of a Z boson or a virtual photon. The invariant mass distribution of the electron and muon pairs is searched for resonances at masses well above the Z boson peak. A very good agreement between simulation and data can be seen in Fig. 3, left. A neutral gauge boson with the same couplings as the SM Z^0 (Sequential Standard Model Z [13]) is excluded up to a mass of 1.9 TeV at 95% C.L. A Randall–Sundrum Kaluza–Klein graviton [14, 15] with a coupling of $k/\bar{M}_{\rm Pl} = 0.1$ is excluded up to 1.8 TeV at 95% C.L. combining the dielectron and the dimuon channel, see figure 3, right. An example of higher mass dimuon candidates is shown, see figure 4.

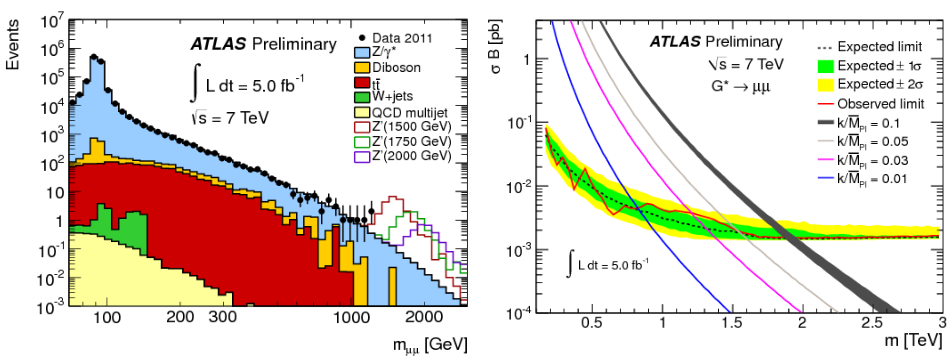

Fig. 3. Left: Dimuon invariant mass ($m_{\mu\mu}$) distributions after final selection, compared with the stacked sum of all expected backgrounds, with two example ZSSM signals overlaid. The bin width is constant in log $m_{\mu\mu}$ [12]. Right: Expected and observed 95% C.L. limits on σB and expected σB for G^* production in dimuon selections. Several σB are shown for couplings ($k/\bar{M}_{\rm Pl}$) in the range of 0.01–0.1. The dashed lines around the theory curve for $k/\bar{M}_{\rm Pl} = 0.1$ represent the theoretical uncertainty which is similar for the other curves as well [12].

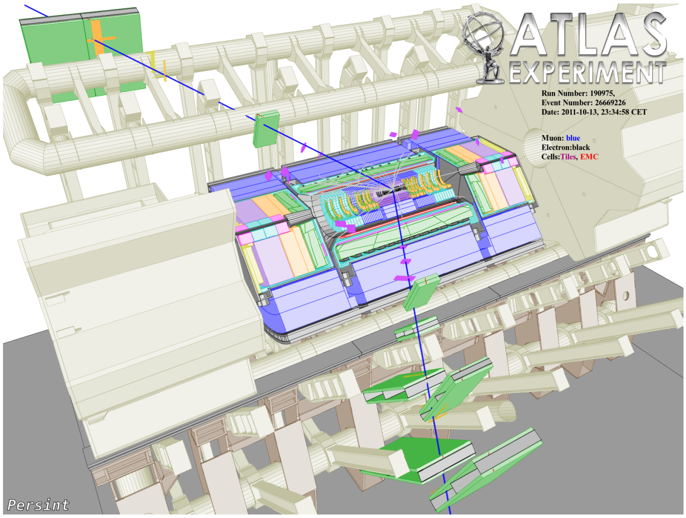

Fig. 4. Event display is for the highest invariant mass dimuon event. The highest momentum muon has a p_{T} of 510 GeV and an (η, ϕ) of (0.37, 3.01). The subleading muon has a p_{T} of 437 GeV and an (η, ϕ) of (0.72, −0.12). The invariant mass of the pair is 959 GeV. Only tracks with $p_{\mathrm{T}} > 0.5$ GeV are shown.

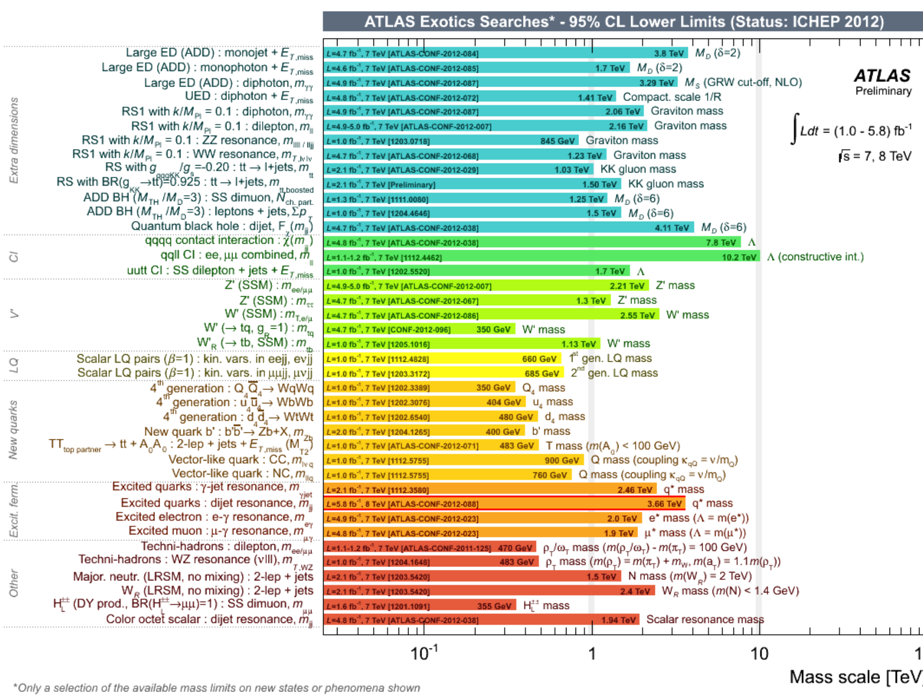

Fig. 5. Overall Status of ATLAS Exotic search results [16].

The second example presented is a search for $t\bar{t}$ resonances, using 2.05 fb^{-1} of pp collisions at $\sqrt{s} = 7$ TeV recorded by ATLAS in 2011. The dilepton, resolved lepton+jets and a boosted lepton+jets topology have been considered. No evidence of a resonance was found. Limits were set on the production cross-section times branching ratio to $t\bar{t}$ for narrow and wide resonances. The search excludes at 95% confidence level narrow leptophobic topcolor Z bosons with masses between 500 and 1150 GeV and wider Kaluza–Klein gluons with masses between 500 and 1500 GeV.

More than 40 analyses have been completed at $\sqrt{s} = 7$ TeV and the first results start to appear for 8 TeV data. No sign of New Physics has been observed, see figure 5.

5. Standard model Higgs search

Three main channels: $H \to ZZ^{(*)} \to 4l$, $H \to \gamma\gamma$ and $H \to WW \to l\nu l\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)} \to 4l$, $H \to \gamma\gamma$, $H \to WW \to l\nu l\nu$ in the 7 TeV data, and results from improved analyses of the channels $H \to ZZ^{(*)} \to 4l$, $H \to \gamma\gamma$ in the 7 TeV data. In the decay channel $H \to ZZ^{(*)} \to 4l$ based on 4.8 $\text{fb}^{-1}$of data recorded with the ATLAS detector at $\sqrt{s} = 7$ TeV during 2011 and 5.8 fb^{-1}recorded at $\sqrt{s} = 8$ TeV during 2012 has been presented. The SM Higgs boson is excluded at 95% C.L. in the mass ranges 131 to 162 GeV and 170 to 460 GeV. An excess of events is observed around $m_H = 125$ GeV, see figure 6, left, whose p_0-value is 0.029% (3.4 standard deviations) in the combined analysis of the two datasets.

In the diphoton channel, an excess of events is observed around the diphoton system invariant mass of about 126.5 GeV with a local significance of $4.5\,\sigma$ as can be seen in figure 6, right.

An excess of events over the expected background is observed corresponding to a local p_0-value of 6×10^4 or 3.2 standard deviations. In a combined analysis of the 2012 data with the 4.7 $\text{fb}^{-1}$of data acquired at $\sqrt{s} = 7$ TeV in 2011, the observed excess in the $H \to WW \to l\nu l\nu$ channel corresponds to a minimum local p_0-value of 3×10^3 or 2.8 standard deviations.

Searches for $H \to ZZ^{(*)} \to 4l$, $H \to \gamma\gamma$, $H \to WW \to l\nu l\nu$, $H \to b\bar{b}$ and $H \to \tau\tau$ have been performed on the 2011 data, while only the $H \to ZZ^{(*)} \to 4l$ and $H \to \gamma\gamma$ searches are improved compared to previous analyses and use both the 2011 and 2012 data. The Standard Model Higgs boson is excluded at the 95% confidence level for masses in the range 110 GeV to 122.6 GeV and 129.7 GeV to 558 GeV. An excess of events is observed for a Higgs boson mass hypothesis near 126.5 GeV. The local significance of this excess is $5.9\,\sigma$, where the expected significance in the presence of a Standard Model Higgs boson for that mass hypothesis is $4.9\,\sigma$

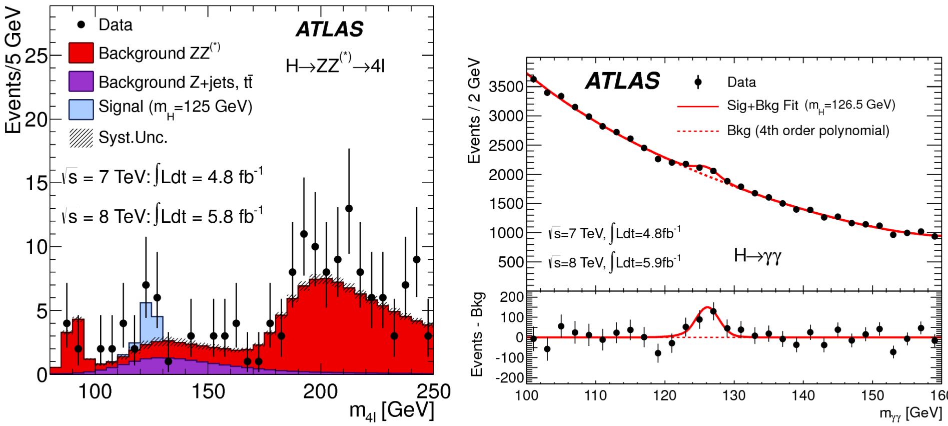

Fig. 6. Left: The distribution of the four-lepton invariant mass, m_{4l}, for the selected candidates compared to the background expectation in the 80–250 GeV mass range for $\sqrt{(s)} = 8$ TeV and $\sqrt{(s)} = 7$ TeV datasets. Error bars represent 68.3% central confidence intervals [17]. Right: Invariant mass distribution for the combined $\sqrt{(s)} = 7$ TeV and $\sqrt{(s)} = 8$ TeV data samples. Superimposed is the result of a fit including a signal component fixed to a hypothesized mass of 126.5 GeV and a background component described by a fourth-order Bernstein polynomial. The bottom inset displays the residual of the data with respect to the fitted background [17].

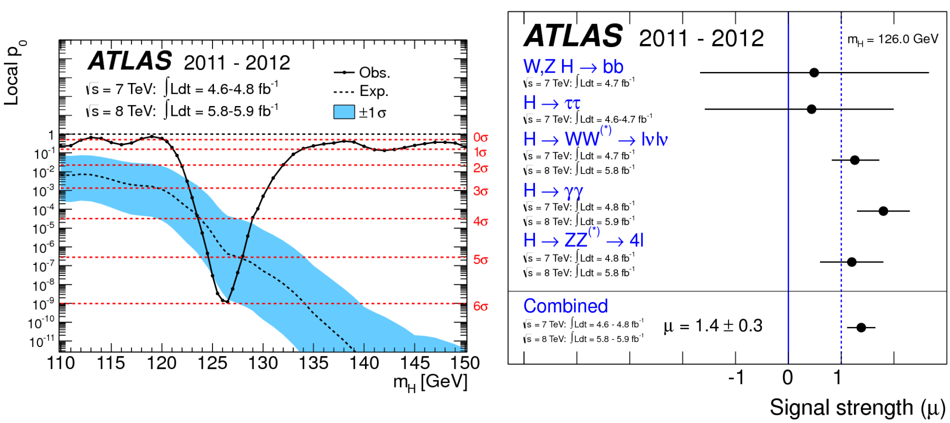

Fig. 7. Left: The observed (solid) local p_0 as a function of m_H in the low mass range. The dashed curve shows the expected local p_0 under the hypothesis of a SM Higgs boson signal at that mass with its $\pm$ one sigma band. The horizontal dashed lines indicate the p-values corresponding to significances of 1 to 6 sigma [17]. Right: Measurements of the signal strength parameter for $m_H = 126$ GeV for the individual channels and their combination [17].

(see p_0-value, figure 7, left). The combined mass measurement derived from the $H \rightarrow ZZ^{(*)} \rightarrow 4l$ and $H \rightarrow \gamma\gamma$ channels is $m_H = 126 \pm 0.4$(stat) $\pm$ 0.4(sys) GeV. The combination of all final states, including the recently updated low mass resolution channels $H \rightarrow WW \rightarrow l\nu l\nu$, $H \rightarrow b\bar{b}$ and $H \rightarrow \tau\tau$, is reported for this data set in terms of the combined signal strength (μ). This is determined to be $= 1.4 \pm 0.3$ computed at a mass of 126 GeV, in agreement with the Standard Model expectation (see figure 7, right).

6. Conclusion

The LHC outstanding exceeds expectations with the integrated luminosity provided to the experiments. ATLAS experiment works very well in all domains. This paper presents the results for approximately 5.0 fb^{-1}collected at $\sqrt{s} = 7$ TeV in 2011 and 5.5 fb^{-1}at $\sqrt{s} = 8$ TeV in 2012. A new Higgs-like boson particle has been discovered, consistent with the SM. A large region of phase space ruled out below TeV for SUSY models and Exotic model.

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