Pis'ma v ZhETF, vol. 113, iss. 4, pp. 221 – 222

Search for new heavy Higgs bosons in ATLAS and CMS experiments at LHC (Mini-review)

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Submitted 15 December 2020
Resubmitted 29 December 2020
Accepted 29 December 2020

DOI: 10.31857/S1234567821040017

Discovery of Higgs boson in 2012 by the ATLAS [1] and CMS [2] experiments finally confirm the truthiness of the Standard Model (SM), but there are still remain many open questions, e.g., SM does not explain the neutrino oscillation and baryon asymmetry, the problem of the particle mass hierarchy etc. This gave rise to the development of new theories which extend the SM – Beyond Standard Models (BSM), in particular, its Higgs sector. These models include the Two Higgs Doublet Model (2HDM) [3], the Minimal Supersymmetric Standard Model (MSSM) [4, 5] and its extension: Next to MSSM (NMSSM) [6], Higgs Triplet Model (HTM) [7], Left Right Symmetric Model (LRSM) [8], the little Higgs model [9], the Georgi–Machacek model [10], scalar singlet dark matter [11] etc. At present, the 2HDM and MSSM are the most used models for the interpretation of the LHC data. These models predicts several particles in the extended Higgs sector, e.g., in 2HDM the electroweak symmetry breaking leads to five Higgs particles: two neutral Higgs bosons that are CP-even (scalar) h, H, one is neutral and CP-odd (pseudoscalar) A, and charged Higgs boson $H^{\pm}$. The model is parametrized by the following parameters, Higgs masses: m_h, m_H, m_A, $m_{H^{\pm}}$, ratio of vacuum expectation values of the two Higgs doublets: $\tan\beta = \frac{v_1}{v_2}$ and the mixing angle α which diagonalizes the mass matrix of the CP even Higgs bosons.

The searches for a new particles from extended Higgs sector were carried out earlier in e^+e^- collisions at LEP [12] and in proton-antiproton collisions at the Tevatron [13, 14]. An intensive searches of the Heavy neutral Higgs bosons (H/A), Charged Higgs boson and Double charged Higgs bosons were performed by the ATLAS and CMS experiments in a wide range of possible values of the resonance masses and for different decay channels and final states. Data collected for LHC Run I and Run II with pp interactions at the center of mass energy $\sqrt{s}$ = 7, 8, 13 TeV were used. Searches of the

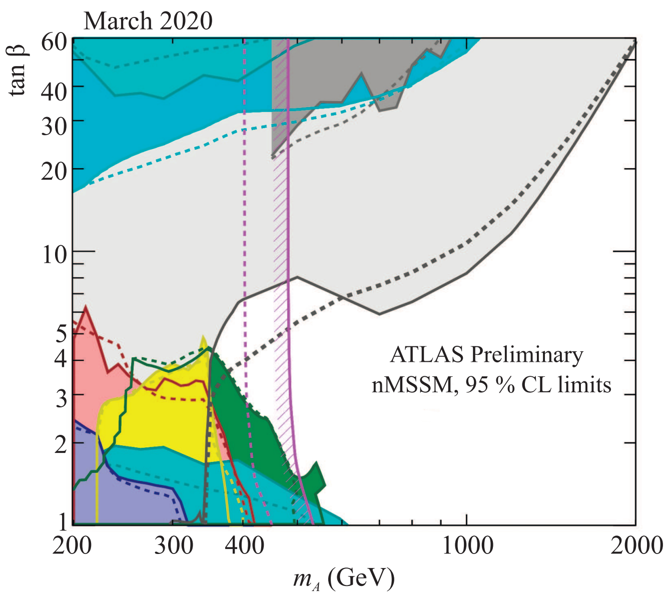

Fig. 1. (Color online) Regions of the $[m_A, \tan\beta]$ plane excluded in the hMSSM model via direct searches for heavy Higgs bosons and fits to the measured rates of observed Higgs boson production and decays [26]. Limits are quoted at 95 % CL and indicated for the data (solid lines) and for the expectation for the SM Higgs sector (dashed lines). The light shaded or hashed regions indicate the observed exclusions obtained in ATLAS experiment: $H/A \to \tau\tau$ [18] (light grey), $H^+ \to \tau\nu$ [21] (cyan), $H^+ \to tb$ [22] (dark cyan), $Hb \to bbb$ [27] (dark grey), $H \to ZZ \to 4l/ll\nu\nu$ [16] (light red), $gg \to A \to Zh$ [28] (yellow), $H \to WW \to l\nu l\nu$ [17] (blue), decay channels combination $H \to hh \to 4b, bbWW, bb\tau\tau, 4W, bb\gamma\gamma, WW\gamma\gamma$ [29] (green) and pink line show the limit obtained with the fits to the measured rates of SM Higgs boson production and decay [30]

heavy neutral resonances (H/A) were performed in the decay channels: $H/A \to VV$ $(V = Z, W, \gamma)$, $\mu\mu$, $\tau\tau$, $t, \bar{t}$ etc., see, e.g., [15–19]. Charged Higgs boson ($H^{\pm}$) were searched in the decays: $H^{\pm} \to \tau\nu, tb, cb, cs, WZ$

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etc., see, e.g., [20–23]. The searches of double charged Higgs boson $H^{\pm\pm}$ were carried out in its decays to the pair of same sign same flavor particles: leptons $e^{\pm}, e^{\pm}$ or $\mu^{\pm}, \mu^{\pm}$ or electroweak gauge bosons, e.g., $W^{\pm}, W^{\pm}$, see, e.g., [24, 25]. The experimental spectra of the kinematic variables (e.g., missing transverse energy or transverse mass) were compared with the SM prediction. No statistically significant deviation of the experimental observations from SM backgrounds were found and the upper limits on the cross section times branching fraction or limits for the resonance mass were derived. Interpretation of the obtained results were performed with different BSM scenarios (2HDM, MSSM, HTM etc.) and the limits on the models parameters were derived.

Summary plot with the constrains on hMSSM parameters $\tan\beta$ and m_A obtained in the ATLAS experiment is presented on the Fig. 1 [26]. Region with the not excluded parameters space is shown with the white color. As it is follows from the results based on these searches for different decay channels the region with $m_A < 340$ GeV is excluded. The analysis of the decay channel $A/H \to \tau\tau$ [18] excludes the region with high $\tan\beta$ values ($\tan\beta \gtrsim 6$). Mass region $m_A < 500\,\text{GeV}$ is indirectly excluded by the measurement of the Higgs boson production and decay rates (shown with violet curve) [30].

In future, LHC Run III followed by the High Luminosity LHC (HL-LHC) will provide much more data and significantly improve the potential to discover a new additional Higgs bosons.

This work was supported by Russian Foundation for Basic Research grant 18-02-00118A.

Full text of the paper is published in JETP Letters journal. DOI: 10.1134/S0021364021040019

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