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Combined Measurement of the Higgs Boson Mass in pp Collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS and CMS Experiments

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A measurement of the Higgs boson mass is presented based on the combined data samples of the ATLAS and CMS experiments at the CERN LHC in the $H \to \gamma\gamma$ and $H \to ZZ \to 4\ell$ decay channels. The results are obtained from a simultaneous fit to the reconstructed invariant mass peaks in the two channels and for the two experiments. The measured masses from the individual channels and the two experiments are found to be consistent among themselves. The combined measured mass of the Higgs boson is $m_H = 125.09 \pm 0.21$ (stat) ± 0.11 (syst) GeV.

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The study of the mechanism of electroweak symmetry breaking is one of the principal goals of the CERN LHC program. In the standard model (SM), this symmetry breaking is achieved through the introduction of a complex doublet scalar field, leading to the prediction of the Higgs boson H [1–6], whose mass m_H is, however, not predicted by the theory. In 2012, the ATLAS and CMS Collaborations at the LHC announced the discovery of a particle with Higgs-boson-like properties and a mass of about 125 GeV [7–9]. The discovery was based primarily on mass peaks observed in the $\gamma\gamma$ and $ZZ \to \ell^+\ell^-\ell'^+\ell'^-$ (denoted $H \to ZZ \to 4\ell$ for simplicity) decay channels, where one or both of the Z bosons can be off shell and where ℓ and ℓ' denote an electron or muon. With m_H known, all properties of the SM Higgs boson, such as its production cross section and partial decay widths, can be predicted. Increasingly precise measurements [10–13] have established that all observed properties of the new particle, including its spin, parity, and coupling strengths to SM particles are consistent within the uncertainties with those expected for the SM Higgs boson.

The ATLAS and CMS Collaborations have independently measured m_H using the samples of proton-proton collision data collected in 2011 and 2012, commonly referred to as LHC Run 1. The analyzed samples correspond to approximately 5 fb^{-1} of integrated luminosity at $\sqrt{s} = 7$ TeV, and 20 fb^{-1} at $\sqrt{s} = 8$ TeV, for each experiment. Combined results in the context of the separate experiments, as well as those in the individual channels, are presented in Refs. [12,14–16].

[*]Full author list given at the end of the article.

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This Letter describes a combination of the Run 1 data from the two experiments, leading to improved precision for m_H. Besides its intrinsic importance as a fundamental parameter, improved knowledge of m_H yields more precise predictions for the other Higgs boson properties. Furthermore, the combined mass measurement provides a first step towards combinations of other quantities, such as the couplings. In the SM, m_H is related to the values of the masses of the W boson and top quark through loop-induced effects. Taking into account other measured SM quantities, the comparison of the measurements of the Higgs boson, W boson, and top quark masses can be used to directly test the consistency of the SM [17] and thus to search for evidence of physics beyond the SM.

The combination is performed using only the $H \to \gamma\gamma$ and $H \to ZZ \to 4\ell$ decay channels, because these two channels offer the best mass resolution. Interference between the Higgs boson signal and the continuum [illegible] ground is expected to produce a downward sh[illegible] signal peak relative to the true value of m[illegible] effect in the $H \to \gamma\gamma$ channel [18–20] is [illegible] few tens of MeV for a Higgs boson with [illegible] SM value, which is small compared to th[illegible] precision. The effect in the $H \to ZZ \to 4\ell$ chann[illegible] expected to be much smaller [21]. The effects of the interference on the mass spectra are neglected in this Letter.

Page 1

The ATLAS and CMS detectors [22,23] are designed to precisely reconstruct charged leptons, photons, hadronic jets, and the imbalance of momentum transverse to the direction of the beams. The two detectors are based on different technologies requiring different reconstruction and calibration methods. Consequently, they are subject to different sources of systematic uncertainty.

The $H \to \gamma\gamma$ channel is characterized by a narrow resonant signal peak containing several hundred events per experiment above a large falling continuum background. The overall signal-to-background ratio is a few

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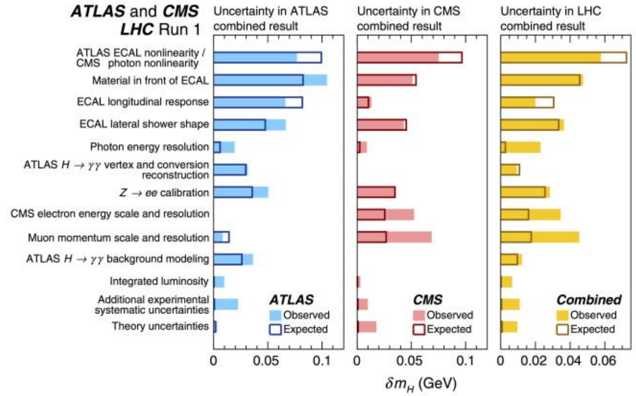

FIG. 3 (color online). The impacts δm_H (see text) of the nuisance parameter groups in Table I on the ATLAS (left), CMS (center), and combined (right) mass measurement uncertainty. The observed (expected) results are shown by the solid (empty) bars.

predictions. Assuming that the negative log-likelihood ratio $-2\ln\Lambda(\mu, m_H)$ is distributed as a χ^2 variable with two degrees of freedom, the 68% confidence level (C.L.) confidence regions are shown in Fig. 4 for each individual measurement, as well as for the combined result.

In summary, a combined measurement of the Higgs boson mass is performed in the $H \to \gamma\gamma$ and $H \to ZZ \to 4\ell$ channels using the LHC Run 1 data sets of the ATLAS

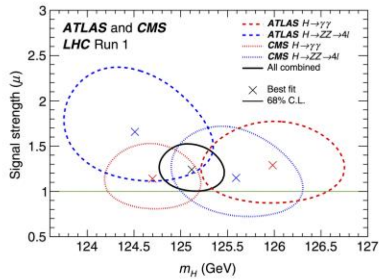

FIG. 4 (color online). Summary of likelihood scans in the 2D plane of signal strength μ versus Higgs boson mass m_H for the ATLAS and CMS experiments. The 68% C.L. confidence regions of the individual measurements are shown by the dashed curves and of the overall combination by the solid curve. The markers indicate the respective best-fit values. The SM signal strength is indicated by the horizontal line at $\mu = 1$.

and CMS experiments, with minimal reliance on the assumption that the Higgs boson behaves as predicted by the SM.

The result is

$$m_H = 125.09 \pm 0.24 \text{ GeV}$$
$$= 125.09 \pm 0.21 \text{ (stat)} \pm 0.11 \text{ (syst) GeV}, \quad (9)$$

where the total uncertainty is dominated by the statistical term, with the systematic uncertainty dominated by effects related to the photon, electron, and muon energy o[illegible] momentum scales and resolutions. Compatibility test[illegible] performed to ascertain whether the measure[illegible] consistent with each other, both between the d[illegible] channels and between the two experim[illegible] the combined results indicate consistency [illegible] measurements within 1σ, while the four Hig[illegible] mass measurements in the two channels of the two [illegible]xperiments agree within 2σ. The combined measurement of the Higgs boson mass improves upon the results from the individual experiments and is the most precise measurement to date of this fundamental parameter of the newly discovered particle.

Page 7

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Page 9

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Pakhotin,[339,‡] R. Patel,[339,‡] A…,[339,‡] J. Roe,[339,‡] A. Rose,[339,‡] A. Safonov,[339,‡] A. Tatarinov,[339,‡] K. A. Ulmer,[339,oo,‡] N. Akchurin,[340,‡] C. Co…den,[340,‡] J. Damgov,[340,‡] C. Dragoiu,[340,‡] P. R. Dudero,[340,‡] J. Faulkner,[340,‡] S. Kunori,[340,‡] K. Lamichhane,[340,‡] S. W. Lee,[340,‡] T. Libeiro,[340,‡] S. Undleeb,[340,‡] I. Volobouev,[340,‡] E. Appelt,[341,‡] A. G. Delannoy,[341,‡] S. Greene,[341,‡] A. Gurrola,[341,‡] R. Janjam,[341,‡] W. Johns,[341,‡] C. Maguire,[341,‡] Y. Mao,[341,‡] A. Melo,[341,‡] P. Sheldon,[341,‡] B. Snook,[341,‡] S. Tuo,[341,‡] J. Velkovska,[341,‡] Q. Xu,[341,‡] M. W. Arenton,[342,‡] S. Boutle,[342,‡] B. Cox,[342,‡] B. Francis,[342,‡] J. Goodell,[342,‡] R. Hirosky,[342,‡] A. Ledovskoy,[342,‡] H. Li,[342,‡] C. Lin,[342,‡] C. Neu,[342,‡] E. Wolfe,[342,‡] J. Wood,[342,‡] F. Xia,[342,‡] C. Clarke,[343,‡] R. Harr,[343,‡] P. E. Karchin,[343,‡] C. Kottachchi Kankanamge Don,[343,‡] P. Lamichhane,[343,‡] J. Sturdy,[343,‡] D. A. 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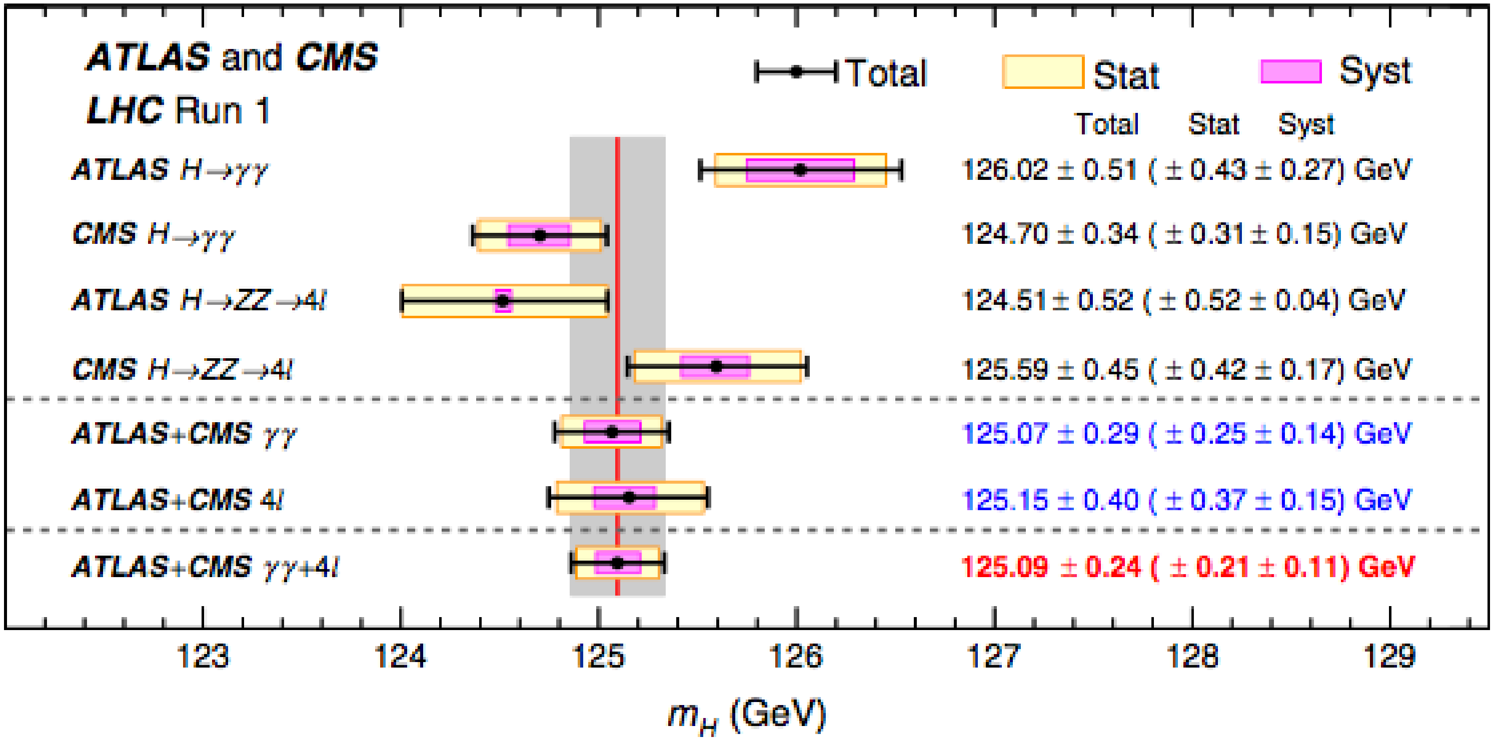
Page 24

Combining Measurements



m_H = 125.09 ± 0.21 (stat) ± 0.11 (syst) GeV