

# Exclusive Production of the MSSM Higgs Bosons at the LHC

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We review the prospects for Central Exclusive Production (CEP) of BSM Higgs bosons at the LHC using forward proton detectors proposed to be installed at 220 m and 420 m from the ATLAS and/ or CMS. Results are presented for MSSM in standard benchmark scenarios and in scenarios compatible with the Cold Dark Matter relic abundance and other precision measurements. Following results of the LHC Higgs boson searches, we investigate a hypothesis that candidates found at a mass of 125 GeV are compatible with light CP-even MSSM Higgs bosons. We show that CEP can give a valuable information about spin-parity properties of the Higgs bosons.

## 1 Introduction

The central exclusive production of new particles has received a great deal of attention in recent years (see [1] and references therein). The process is defined as  $pp \rightarrow p \oplus \phi \oplus p$  and all of the energy lost by the protons during the interaction (a few per cent) goes into the production of the central system,  $\phi$ . The final state therefore consists of a centrally produced system (e.g. dijet, heavy particle or Higgs boson) coming from a hard subprocess, two very forward protons and no other activity. The ' $\oplus$ ' sign denotes the regions devoid of activity, often called rapidity gaps. Studies of the Higgs boson produced in CEP used to form a core of the physics motivation for upgrade projects to install forward proton detectors at 220 m and 420 m from the ATLAS [2] and CMS [3] detectors, see [1]. At the moment, only 220 m stations are considered to be installed in ATLAS [4]. Proving that the detected central system is the Higgs boson coming from the SM, MSSM or other BSM theories will require measuring precisely its spin, CP properties, mass, width and couplings.

In [5] we have presented detailed results on signal and background predictions of CEP production (based on calculations in [6] and the FeynHiggs code [7, 8]) of the light ( $h$ ) and heavy ( $H$ ) Higgs bosons which have then been updated in [9]. Changes between these two publications are described in [9] and summarized in [10]. Four luminosity scenarios are considered: “60 fb<sup>-1</sup>” and “600 fb<sup>-1</sup>” refer to running at low and high instantaneous luminosity, respectively, using conservative assumptions for the signal rates and the experimental efficiencies (taken from [11]); possible improvements on the side of theory and experiment could allow for scenarios where the

event rates are enhanced by a factor 2, denoted by “60 fb<sup>-1</sup> eff×2” and “600 fb<sup>-1</sup> eff×2”.

## 2 Results and LHC exclusion regions

Standard benchmark scenarios designed to highlight specific characteristics of the MSSM Higgs sector, so called  $M_h^{max}$  and no-mixing scenarios, do not necessarily comply with other than MSSM Higgs sector constraints. Scenarios which fulfill constraints also from electroweak precision data, B physics data and abundance of Cold Dark Matter (CDM) are the so called CDM benchmark scenarios [12]. As observed and discussed in [9], the 5 $\sigma$  discovery and 3 $\sigma$  contours show in general similar qualitative features as the results in the  $M_h^{max}$  and no-mixing scenario. Since publications [9] and [10], the results have been updated by adding the exclusion regions coming from LHC searches for MSSM signal (see Fig. 1). These exclusion regions are obtained using the code HiggsBounds version 3.6.0 [13]. Compared to previous results with Tevatron exclusion regions ([9, 10]), the allowed region for MSSM has now significantly shrunk.

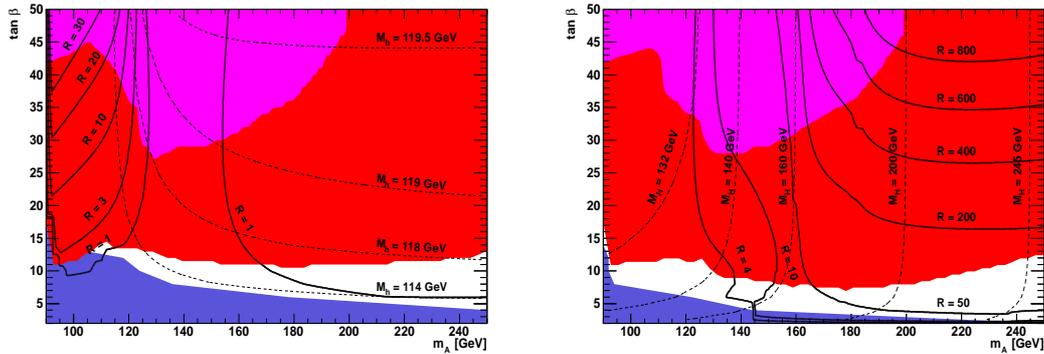


Figure 1: Ratios of MSSM to SM cross sections and mass  $M_h$  ( $M_H$ ) contours for  $h(H) \rightarrow b\bar{b}$  channel in CEP production in the  $M_A - \tan \beta$  plane of the MSSM are shown on left (right) within the no-mixing ( $M_h^{max}$ ) benchmark scenario. The lighter (dark) shaded region corresponds to the parameter region excluded by the LEP (Tevatron) Higgs boson searches, the smaller region on top corresponds to the Tevatron Higgs boson search.

## 3 Hypothesis of a Higgs boson at 125 GeV

Presently a big effort is put into Higgs boson searches at the LHC, both at SM and beyond SM. While the MSSM exclusion regions are already accounted for in our results (see e.g. Fig. 1), the results of the SM Higgs boson search on the data samples collected in 2011 (up to 4.9 fb<sup>-1</sup>) are as follows: both ATLAS ([14]) and CMS ([15]) exclude similar mass regions and both observe an excess of the signal over background in the same mass region. After combining all decay channels, ATLAS (CMS) declare the excess at  $M_h=126$  GeV (125 GeV) with a local significance of 2.5 $\sigma$  (2.8 $\sigma$ ). The global probability for such an excess found in the search range  $110 < M_h < 600$  GeV, in the absence of a signal, is 2.2 $\sigma$  (2.1 $\sigma$ ). A natural question then is how

the observation of Higgs candidates in this mass range would affect our results. Let us work with a hypothesis that Higgs candidates are found at the mass of  $125 \pm 3$  GeV (1.5 GeV corresponds to the experimental uncertainty thanks to the fact that most of the signal comes from the  $\gamma\gamma$  decay channel, being the most precise in the mass measurement; the theory uncertainty is estimated in [16]). This SM Higgs mass range  $122 < M_h < 128$  GeV is compatible with the allowed mass range  $122.5 < M_h < 127.5$  GeV when combining exclusion limits found at 95% C.L. by both experiments. The effect of this hypothesis is shown in Fig. 2 (now with the y-axis in the logarithmic scale) from which two main facts may be drawn: i) CEP MSSM signal still survives the as yet provided exclusion limits. In the allowed region, a significance of  $3\sigma$  may be achieved for the highest luminosity scenario, ii) MSSM is in agreement with the tentative hints at 125 GeV, although the allowed region may shrink further with time.

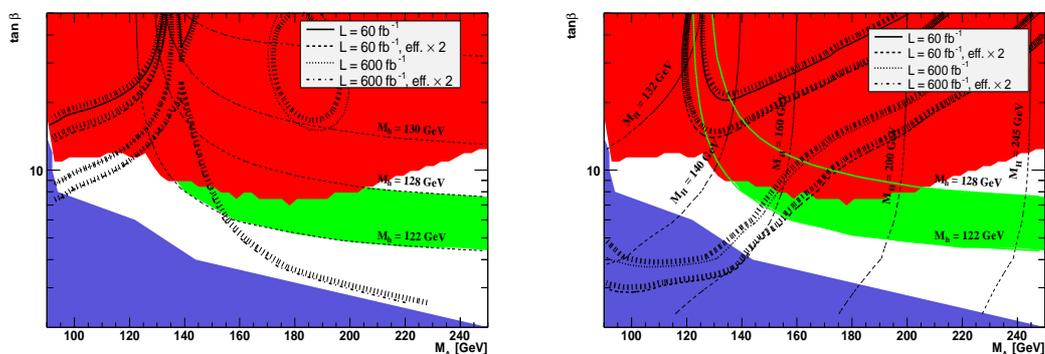


Figure 2:  $3\sigma$  evidence and mass  $M_h$  ( $M_H$ ) contours for  $h(H) \rightarrow b\bar{b}$  channel in CEP production in the  $M_A - \tan\beta$  plane of the MSSM are shown on left (right) within the  $M_h^{\max}$  benchmark scenario. The results are shown for four assumed effective luminosities (see the text). The lighter (dark) shaded region corresponds to the parameter region excluded by the LEP (Tevatron) Higgs boson searches. The region  $122 < M_h < 128$  GeV refers to the hypothesis of Higgs bosons found at 125 GeV with assumed theory and experimental uncertainties.

## 4 Coupling structure and spin-parity determination

Standard methods to determine the spin and the CP properties of Higgs bosons at the LHC rely to a large extent on the coupling of a relatively heavy Higgs boson to two gauge bosons. In particular, the channel  $H \rightarrow ZZ \rightarrow 4l$  - if it is open - offers good prospects [17]. In a study [18] of the Higgs production in the weak vector boson fusion it was found that for  $M_H = 160$  GeV the  $W^+W^-$  decay mode allows the discrimination between a pure CP-even (as in the SM) and a pure CP-odd tensor structure at a level of  $4.5$ – $5.3\sigma$  using about  $10 \text{ fb}^{-1}$  of data (assuming the production rate is that of the SM, which is in conflict with the latest search limits from the Tevatron [19]). A discriminating power of  $2\sigma$  was declared in the  $\tau^+\tau^-$  decay mode at  $M_H = 120$  GeV and luminosity of  $30 \text{ fb}^{-1}$ .

The situation is different in MSSM: for  $M_H \approx M_A \gtrsim 2M_W$  the lightest MSSM Higgs boson couples to gauge bosons with about SM strength, but its mass is bounded to a region  $M_h \lesssim$

135 GeV [8], where the decay to  $WW^{(*)}$  or  $ZZ^{(*)}$  is difficult to exploit. On the other hand, the heavy MSSM Higgs bosons decouple from the gauge bosons. Consequently, since the usually quoted results for the  $H \rightarrow ZZ/WW \rightarrow 4l$  channels assume a relatively heavy ( $M_H \gtrsim 135$  GeV) SM-like Higgs, these results are not applicable to the case of the MSSM. The above-mentioned analysis of the weak boson fusion with  $H \rightarrow \tau^+\tau^-$  is applicable to the light CP-even Higgs boson in MSSM but due to insignificant enhancements compared to the SM case no improvement can be expected.

An alternative method which does not rely on the decay into a pair of gauge bosons or on the production in weak boson fusion would therefore be of great interest. Thanks to the  $J_z = 0$ , C-even, P-even selection rule, the CEP Higgs boson production in MSSM can yield a direct information about spin and CP properties of the detected Higgs boson candidate and in addition, a small number of such events is sufficient [9].

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