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Exclusive production of the BSM Higgs bosons at the LHC *

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Abstract

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, in scenarios compatible with the Cold Dark Matter relic abundance and other precision measurements, and for SM with a fourth generation of fermions. We show that CEP can give a valuable information about spin-parity properties of the Higgs bosons.

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1 Introduction

The central exclusive production (CEP) of new particles has received a great deal of attention in recent years (see [1] and references therein). The process is defined as $pp \to p \oplus \phi \oplus p$ and all of the energy lost by the protons during the interaction (a few per cent) goes into the production of the central system, ϕ. 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 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] and [4]. Proving, however, 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.

2 Updates to the previous analyses

In [5] we have presented detailed results on signal and background predictions of CEP production (based on calculations in [6]) of the light (h) and heavy (H) Higgs bosons. A recent update of results from [5] has been presented in [7]. Changes between these two publications can be briefly summarized as:

- The NLO corrections added to the background associated with bottom-mass terms in the Born amplitude [8] result in a suppression of the LO contribution by a factor of two or more for larger masses.
- The use of the recent version of FeynHiggs code [9]: all three main changes increase the bottom loop contribution and hence the $gg \to h(H)$ production rate: the running of the bottom mass $m_b(m_b)$ rather than $m_b(m_t)$ in the bottom Yukawa coupling; the improved corrections to the bottom loop in the $\phi \to gg$ calculation; change to a running top mass, efectively decreasing the top-loop contribution.

These changes result in enlarging the regions covered by 5σ or 3σ contours compared to those in [5]. The change in the signal cross section is visualised as ratios of the MSSM to SM cross sections shown in Fig. 1, and has to be compared with Figs. 2 and 7 of [5]. We conclude that the MSSM cross section increased at lower M_A (all M_A) for h (H).

Four luminosity scenarios are considered: "60 fb^{-1}" and "600 fb^{-1}" refer to running at low and high instantaneous luminosity, respectively, using conservative assumptions for the signal rates and the experimental efficiencies (taken from [10]); 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^{-1} eff$\times$2" and "600 fb^{-1} eff$\times$2".

3 Cold Dark Matter benchmark scenarios

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

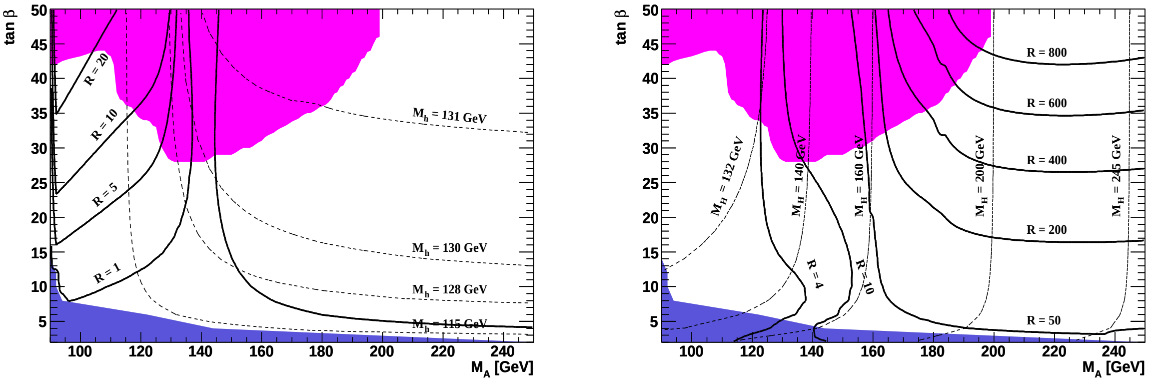

Figure 1: Contours for the ratio of signal events in the MSSM to those in the SM and for the mass values M_h (M_H) for $h(H) \to b\bar{b}$ channel in CEP are shown on left (right) for the $M_h^{\max}$ scenario with $\mu = 200$ GeV. The dark (lighter) shaded region corresponds to the parameter region excluded by the LEP (Tevatron) Higgs boson searches.

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 [11]. As observed and discussed in [7], the 5σ discovery and 3σ contours show in general similar qualitative features as the results in the $M_h^{\max}$ and no-mixing scenario. In Fig. 2 the 5σ discovery contours are shown for the $b\bar{b}$ decay channel in the P3 plane. For the ligh Higgs boson h, a 5σ discovery is possible for $M_A \lesssim 125$ GeV and $\tan\beta \gtrsim$10, depending on luminosity. The LEP exclusion regions are observed to be complementary to the parameter space covered by CEP Higgs boson production. For the heavy Higgs boson H, the 5σ discovery can be reached up to $M_H \lesssim 260$ GeV at large $\tan\beta$ and high luminosity. At low luminosity, the reach extends only up to $M_H \lesssim 210$ GeV, and it is largely excluded by the Tevatron searches.

4 Model with a fourth generation of fermions

A rather simple example of physics beyond SM is a model “SM4” which extends the SM by a fourth generation of heavy fermions, see for instance [12]. The masses of the fourth generation quarks in such a scenario need to be significantly larger than the mass of the top quark. As a consequence, the effective coupling of the Higgs boson to two gluons in the SM4 is to good approximation three times larger than in the SM and the partial decay width $\Gamma(H \to gg)$ are larger by a factor of 9, giving rise to a corresponding shift in the total Higgs width and therefore all the decay branching ratios, see for instance [13]. The total decay width in the SM4 and the relevant decay branching ratios in terms of the corresponding quantities in the SM have been evaluated in [7]. Recent combined analyses of the CDF and DØ collaborations [14], and the LEP Higgs searches [15] (data from [15] were re-interpreted using the HiggsBounds program [16]) exclude Higgs bosons of the SM4 at the 95% C.L. in regions 130 GeV $\lesssim M_{H^{SM4}} \lesssim$ 210 GeV and $M_{H^{SM4}} \lesssim$ 112 GeV, respectively.

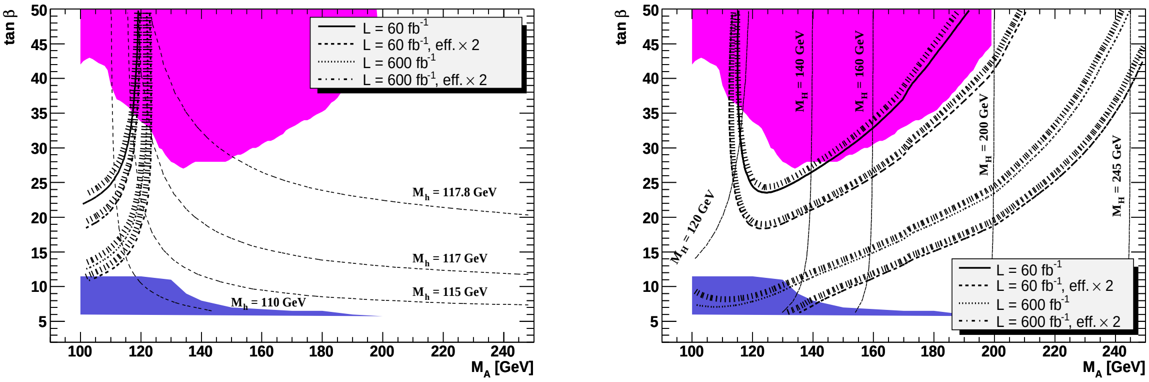

Figure 2: 5σ discovery and mass M_h (M_H) contours for $h(H) \to b\bar{b}$ channel in CEP production in the $M_A - \tan\beta$ plane of the MSSM are shown on left (right) within the CDM benchmark scenario **P3**. The results are shown for four assumed effective luminosities (see the text). The dark (lighter) shaded region corresponds to the parameter region excluded by the LEP (Tevatron) Higgs boson searches.

As discussed in [7], the $b\bar{b}$ channel shows that even at rather low luminosity the allowed region of 112 GeV $\lesssim M_{H^{SM4}} \lesssim$ 130 GeV can be covered by the CEP Higgs boson production. The still allowed region of $M_{H^{SM4}} >$ 210 GeV cannot be covered due to a low BR($H^{SM4} \to b\bar{b}$). The $\tau^+\tau^-$ channel in the allowed mass region reaches a sensitivity of about 2σ at luminosity of 60 fb^{-1}, while it can exceed 5σ at 600 fb^{-1}.

5 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 $H \to ZZ \to 4l$ - if it is open - offers good prospects in this respect [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 two extreme scenarios of a pure CP-even (as in the SM) and a pure CP-odd tensor structure at a level of 4.5–5.3σ using about 10 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 2σ was declared in the $\tau^+\tau^-$ decay mode at $M_H = 120$ GeV and luminosity of 30 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 [20], 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 $H \to ZZ/WW \to 4l$ 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 $H \to \tau^+\tau^-$ 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 Higss boson production in MSSM can yield a direct information about spin and CP properties of the detected Higgs boson candidate. It is also expected, in particular in a situation where a new particle state has also been detected in one or more of the conventional Higgs search channels, that already a small yield of CEP events will be sufficient for extracting relevant information on the spin and $\mathcal{CP}$-properties of the new state [7].

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References

[1] FP420 R&D Collab., *J. Inst.* **4** (2009) T10001, arXiv:0806.0302 [hep-ex].

[2] ATLAS Collab., *J. Inst.* **3** (2008) S08003.

[3] CMS Collab., *J. Phys.* **G 34** (2007) 995, CERN-LHCC-2006-021, CMS-TDR-008-2 (2007).

[4] The AFP project in ATLAS, Letter of Intent, see e.g.:
C. Royon [RP220 Collaboration], arXiv:0706.1796 [physics.ins-det];
M. Tasevsky, *Nucl. Phys. Proc. Suppl.* **179-180** (2008) 187.

[5] S. Heinemeyer *et al.*, *Eur. Phys. J.* **C 53** (2008) 231.

[6] V.A. Khoze, A.D. Martin and M.G. Ryskin, *Eur. Phys. J.* **C 23** (2002) 311, arXiv:0802.0177[hep-ph].

[7] S. Heinemeyer *et al.*, arXiv:1012.5007 [hep-ph], accepted by Eur. Phys. J. **C**.

[8] A.G. Shuvaev *et al.*, *Eur. Phys. J.* **C 56** (2008) 467.

[9] S. Heinemeyer, W. Hollik and G. Weiglein, *Comp. Phys. Commun.* **124** (2000) 76.

[10] M. Albrow *et al.*, CERN-LHCC-2006-039/G-124 (2006), CMS Note 2007/002, TOTEM Note 06-5.

[11] J. Ellis *et al.*, *JHEP* **0710** (2007) 092, arXiv:0709.0098 [hep-ph].

[12] P. Frampton *et al.*, *Phys. Rept.* **330** (2000) 263; B. Holdom *et al.*, *PMC Phys.* **A 3** (2009) 4.

[13] G. Kribs, T. Plehn, M. Spannowsky and T. Tait, *Phys. Rev.* **D 76** (2007) 075016.

[14] TEVNPH Working Group, for the CDF Collab. and DØ Collab., CDF note 10101, DØ note 6039.

[15] ALEPH, DELPHI, OPAL and L3 Collab. and LEP Working group for Higgs boson searches, *Phys. Lett.* **B 565** (2003) 61; *Eur. Phys. J* **C 47** (2006) 547.

[16] P. Bechtle *et al.*, *Comput. Phys. Commun.* **181** (2010) 138, arXiv:0811.4169 [hep-ph].

[17] V. Buescher and K. Jakobs, *Int. J. Mod. Phys.* **A 20** (2005) 2523.

[18] C. Ruwiedel, N. Wermes and M. Schumacher, *Eur. Phys. J.* **C 51** (2007) 385.

[19] CDF abd D0 collaborations, *Phys. Rev. Lett.* **104** (2010) 061802, arXiv:1007.4587 [hep-ex].

[20] G. Degrassi, S. Heinemeyer, W. Hollik, P. Slavich and G. Weiglein, *Eur. Phys. J.* **C 28** (2003) 133.