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Searches for new processes in the scalar sector at the CMS experiment

Tristan du Pree (on behalf of the CMS Collaboration)

Abstract

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PROCEEDINGS OF SCIENCE

Searches for new processes in the scalar sector at the CMS experiment

Tristan du Pree (on behalf of the CMS Collaboration)[∗ †]
Centre for Cosmology, Particle Physics and Phenomenology (CP3)
Université catholique de Louvain
Chemin du Cyclotron, 2
B-1348, Louvain-la-Neuve
Belgium
E-mail: tristan.dupree@uclouvain.be

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[∗]Speaker.

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1. Introduction

After the discovery of a particle consistent with the boson predicted by the Brout-Engler-Higgs mechanism, the sector of electroweak symmetry breaking is now explored to search for processes beyond the standard model of particle physics. Firstly, measurements of the couplings of the observed 125 GeV boson are used to test the consistency of the theoretical predictions of various production and decay mechanisms [1]. Secondly, rare decays are employed to search for heavy particles via their possible off-shell contributions to decay amplitudes. Thirdly, the search for invisible decays allows to test the coupling of this particle to Dark Matter.

Besides tests of its properties, the observed new particle also motivates searches for an extended scalar sector, with extra singlets or doublets. Examples of such models are the MSSM (the minimal supersymmetric extension of the standard model), NMSSM (next-to-MSSM), and more general 2HDMs (Two-Higgs-Doublet Models). The combination of the measurements of its couplings with the direct searches allows to test a broad range of parameter space of various models.

These proceedings describe recent results on searches in the scalar sector at the CMS experiment [2], using pp collision data collected at the LHC at centre-of-mass energies of 7 and 8 TeV.

2. Searches for rare H-boson decay modes

The H$\to$Zγ process is a rare decay: the branching ratio is expected to be only 0.1%. However, heavy particles, beyond the standard model of particle physics, could modify the branching ratio via offshell contributions in loop diagrams. The search is performed in the Z($\ell\ell$)γ final state, with ℓ =e, μ, using in total 24.6 fb^{-1} of data collected at 7 and 8 TeV. The invariant mass distribution of the dilepton+photon system is used to search for a narrow resonance, as shown in Fig. 1 (left), and the sensitivity is enhanced by performing the search in five event categories, depending on the properties of the jets, photons, and leptons in the events. With no excess observed over the background, a cross section times branching ratio $>$ 9.5 times the expected for M_{H} = 125 GeV is excluded at 95% C.L. [3].

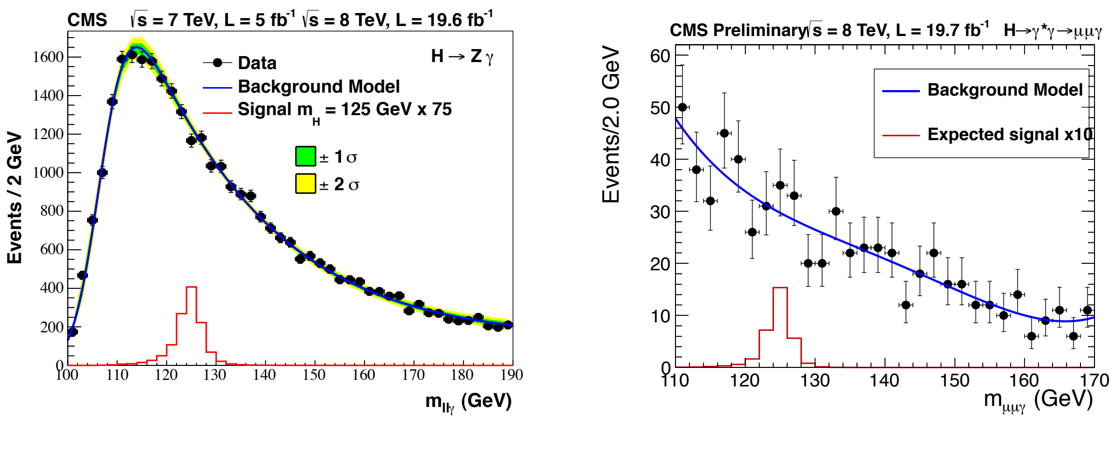

Figure 1: The invariant mass distributions of the dilepton+photon system for the H$\to$Z($\ell\ell$)γ search (left) and the H$\to$ $\gamma^{*}(\mu\mu)\gamma$ search (right).

Another rare H-boson decay goes through the H→ $\gamma^*(\mu\mu)\gamma$ channel. Various amplitudes contribute to this Dalitz decay, and this search is possibly sensitive to new resonances decaying to two muons. With respect to the search for Zγ, the dimuon mass is required to be small, $M_{\mu^+\mu^-} < 20$ GeV, and again the dimuon+photon invariant mass is used to search for a narrow peak. As shown in Fig. 1 (right), no excess with respect to the background is found in the 120-150 GeV mass range with 19.7 fb^{-1} of data collected at 8 TeV, and for $M_{\rm H} = 125$ GeV a branching ratio > 11 times the expectation is excluded [4].

Furthermore, the direct search for invisible decays exploits the associated production in vector-boson-fusion ('VBF') and 'Higgs-strahlung' final states. These studies are of interest as limits on Dark Matter in 'Higgs portal' models, in which these invisible particles couple to the H boson, thereby providing complementary information to searches for Dark Matter. Combining the VBF, Z(bb)H, and Z($\ell\ell$)H channels, the invisible branching ratio is excluded to be > 58% [5].

3. Searches for additional scalar bosons

A direct probe for modified scalar sectors is the search for a minimal extension of the standard model via the addition of an electroweak singlet field. Due to mixing the couplings of the light h scale as $\mu_{\rm h} = C^2$ and the couplings of the heavy H scale as $C'^2 = 1 - \mu_{\rm h}$. Using H→Z($\ell\ell$)Z($\nu\nu$) alone, a SM-like heavy H boson is excluded up to a mass of 1 TeV, and assuming no couplings to other new particles, large values of C'^2 are ruled out, as shown in Fig. 2 (left).

Another common extension of the scalar sector is the 2HDM, an effective theory with two complex scalar doublets. After electroweak symmetry breaking, these models contain five physical scalar particles: three neutral (the SM-like h, the CP-even H, the CP-odd A) and two charged (H$^\pm$). Couplings of these models are described by $\tan\beta$ (the ratio of the vacuum expectation values) and α (the measure of mixing between h and H). In Type I of these models, the doublets couple to the vector bosons and the fermions, repectively; in Type II of these models, the doublets couple to

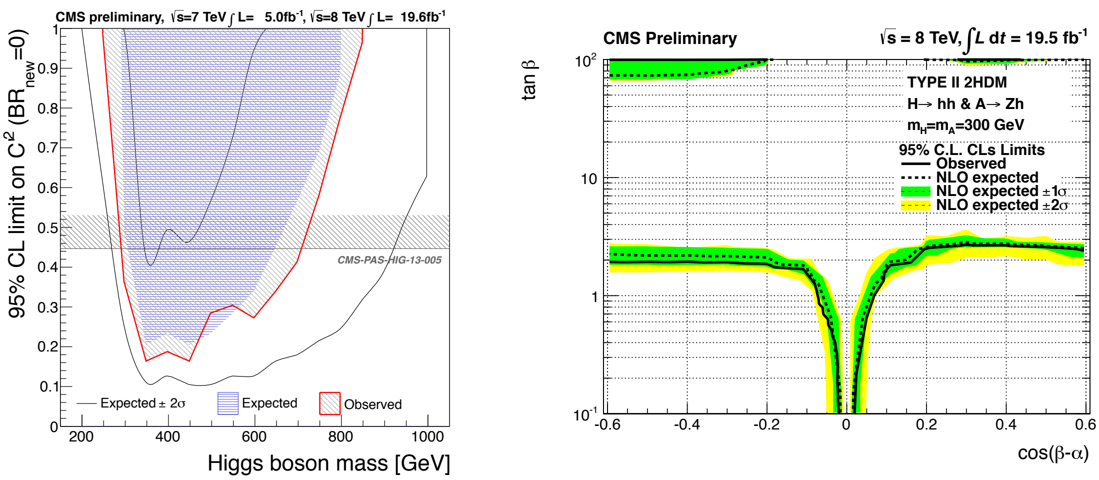

Figure 2: Limits on the coupling C' of the additional electroweak singlet (left) and on the couplings α and β in Type II 2HDMs (right).

the up-type and down-type quarks. The observation of a 125 GeV Higgs boson, already provides indirect constraints to these models [6].

Direct searches for 2HDMs are performed with the H→hh and A→Zh production mechanisms, in the invariant mass range between two Higgs bosons and two top quarks, i.e. $260 < M_{\mathrm{H}} < 360$ GeV. Multiple final states are employed, selecting various numbers of leptons, photons, b-tagged and τ-tagged jets, as well as missing transverse energy, thereby probing various production and decay mechanisms. Combining these searches, direct limits are obtained on β and α in both types of 2HDMs [7], and the combined limit on the Type II 2HDM is shown in Fig. 2 (right).

The resonant production of two Higgs bosons in a single event, via X→hh, has recently been searched for in the final state in which one boson decays into photons and the other boson into b jets. This search combines the advantage of the good resolution of the h→ $\gamma\gamma$ final state with the large h→bb branching ratio. For $M_{\gamma\gamma\mathrm{bb}} > 400$ GeV the $\gamma\gamma$bb invariant mass is used for the search, and the resolution is improved by employing a kinematic fit; for $M_{\gamma\gamma\mathrm{bb}} < 400$ GeV the diphoton mass is used to search for an excess. No such excess is observed in the mass range 260-1100 GeV, and limits are set on various models that predict the production of X→hh, as shown in Fig. 3 (left). In particular, models with warped extra dimensions, and a radion scale of 1 TeV, are excluded with mass less than 970 GeV [8].

4. Searches for MSSM and NMSSM

The scalar sector of the MSSM is a particular 2HDM of Type II. Its phenomenology is usually described in terms of $\tan\beta$ and M_{A}, and the observation of the 125 GeV boson already sets constraints on M_{A}, e.g. in simplified MSSM [9].

Examples of direct searches by CMS for production of neutral scalar bosons in the context of MSSM are the final states with $\Phi \to$bb [10] and $\Phi \to \mu\mu$ [11]. At large values of $\tan\beta$, the coupling to down-type quarks is enhanced and therefore these searches are performed in final states with extra b jets in the final state. A recent result is the search for MSSM with a neutral Higgs boson

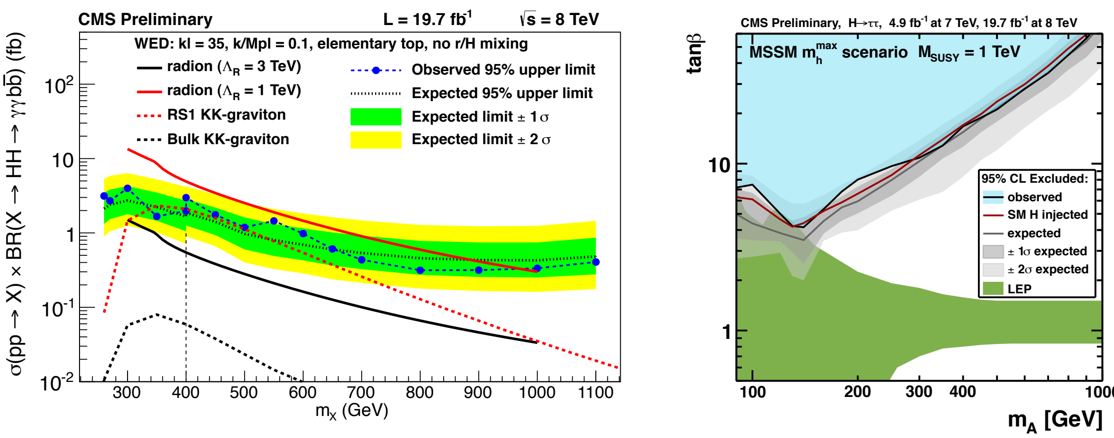

Figure 3: Limits on the cross section for X→hh production in the h(bb)h($\gamma\gamma$) final state (left) and on M_{A} and $\tan\beta$ in the $\Phi \to \tau\tau$ final state (right).

in the $\Phi \rightarrow \tau\tau$ decay. In combination with the results from LEP, in the m_h^{max} scenario, these lead to exclusions of $M_A < 140$ GeV, for almost the full range of $\tan\beta$, as shown in Fig. 3 (right). The upper limits, on the cross section times branching ratio, are also presented separately for different b-jet multiplicities, such that the results are available for model-independent interpretations [12].

The production of charged Higgs bosons can originate, in MSSM and for $M_H < M_t$, from the decay of $t\bar{t}$ pairs. Final states of both $t\bar{t} \rightarrow$HbWb and $t\bar{t} \rightarrow$HbHb are possible, depending on the $t \rightarrow$Hb branching ratio, and the charged $H^{\pm} \rightarrow \tau^{\pm}\nu$ decay is significant for a large range of $\tan\beta$. The search for this process combines various channels: the fully hadronic, the e-τ, and the e-μ final states. Assuming BR($H^{\pm} \rightarrow \tau^{\pm}\nu = 1$), and using 4.9 fb^{-1} at 7 TeV, branching ratios BR($t \rightarrow H^{\pm}$b)> 2-4% are excluded at 95% C.L. in a mass range of $80 < M_H < 160$ GeV [13].

Another supersymmetric model is NMSSM which, compared to MSSM, has an additional singlet that extends the scalar sector even further, with an additional CP-even and a CP-odd scalar boson. In that case, a larger phenomenology opens up, with neutral scalar bosons lighter than 125 GeV that are experimentally not yet excluded in NMSSM. Recently, a search was performed for $h_{12} \rightarrow 2a_1 \rightarrow 4\mu$, with $2M_\mu < M_a < 2M_\tau$, setting limits on various BSM models [14].

On the longer term, with enhanced luminosity at 14 TeV, direct searches for H→ZZ and A→Zh will be continued. Prospective studies show sensitivity to regions of paramater space that are currently not yet excluded by indirect searches. In particular, intermediate values of $\tan\beta$ are foreseen to be probed, as well as values closer to $\cos(\beta-\alpha) \rightarrow 0$ [15].

5. Conclusions

After the discovery of a Higgs boson, the studies of its properties now enter the domain of precision measurements. Its properties, also its rare decays and invisible decays, agree with the scalar boson predicted by the Brout-Englert-Higgs mechanism, which constrains the parameter space for physics beyond the standard model of particle physics in the scalar sector. Besides these measurements, a variety of direct searches for other scalar bosons is being conducted at CMS; various models with extended scalar sectors have recently been searched for, setting limits on the realizations of e.g. MSSM, NMSSM, and 2HDMs. Also with increased luminosity, at higher centre-of-mass energy, the scalar sector will provide a large variety of probes to extensions of the standard model of particle physics.

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