STANDARD MODEL HIGGS OBSERVABILITY WITH ATLAS AND CMS

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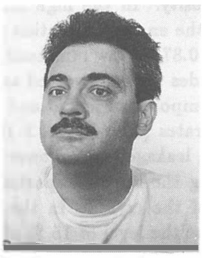

Abstract

The observability of the Standard Model Higgs boson at LHC is discussed. The Higgs search is performed in the mass range from 80 GeV (LEP II limit) up to the TeV region using the two LHC detectors, ATLAS and CMS, as described in the recent Technical Proposals [1, 2]. One will discuss the low mass range, from 80 GeV up to 130 GeV, where the Higgs is observed in direct or associated production, while decaying to $\gamma\gamma$ or $b\bar{b}$. The mass range from 130 GeV up to 1 TeV is then discussed. A special emphasis is put on the experimental problems in the low mass range, and the corresponding potentials of the two experiments. The strongly interacting Higgs sector is briefly discussed at the end.

1 80 GeV $\leq m_H \leq$ 130 GeV

1.1 Direct and associated production $t\bar{t}H, WH,\ H \rightarrow \gamma\gamma$

In this mass range, the Higgs is extremely narrow, and one needs the ultimate mass resolution to observe the signal above the irreducible background made of $q\bar{q}, gg \rightarrow \gamma\gamma$, and of the bremsstrahlung contribution, i.e. $gq \rightarrow \gamma\gamma$. To achieve that goal, an accurate energy measurement is obtained in ATLAS using the Liquid Argon calorimeter (the individual photon energy resolution goes as $10\%/\sqrt{E}$), and in CMS with $PbWO_4$ crystals ($2\%/\sqrt{E}$ at low luminosity). The angular measurement is obtained in ATLAS by using a presampler device combined with the information of the longitudinal segments of the calorimeter, while CMS performs a primary vertex reconstruction at low luminosity. In the high luminosity regime, the adjunction of a preshower is needed, deteriorating the energy resolution ($5\%/\sqrt{E}$). The final mass resolution for m_H=110 GeV is 0.54 GeV (resp. 0.87) at low luminosity (resp. high) for CMS, and 1.25 GeV (resp. 1.33) for ATLAS, which includes both converted and unconverted photons, unlike CMS.

The reducible backgrounds are composed of jet-jet and γ-jet events, where final jets can fake photons, and have extremely high rates ($R_{jj}/R_{\gamma\gamma} \simeq 2\ 10^6$ and $R_{\gamma j}/R_{\gamma\gamma} \simeq 8\ 10^2$). After the combined use of isolation, hadronic leakage, and shower profile informations, one is left with isolated π^0, which are rejected using the strip compartment of the calorimeter in the case of ATLAS, and the fine granularity of the crystals in the case of CMS, yielding at the end a reducible background contribution at the level of 15 % of the irreducible background (Fig. 1).

A potentially dangerous background for $m_H \simeq m_Z$ is the $Z \rightarrow e^+e^-$ decay mode which is resonant.This has been studied by ATLAS, showing that a track veto efficiency of 99.8 % per track is necessary to reduce this background below 10 % of the signal (Fig. 2). This strong requirement seems to be achievable, at the expense of a loss in signal efficiency of 10% [3].

The overall efficiencies are 77% per photon for ATLAS, and 64% for CMS, since converted photons are not taken into account in CMS study [4]. Due to the high central magnetic field for CMS, the converted photons response is distorted, and to account for part of them is quite challenging (Fig. 3).

Finally, and under the same assumptions for the cross-sections, CMS yields statistical significance 30% better than ATLAS at low luminosity, and only 10% at high luminosity [5].
The associated production $t\bar{t}H, WH$ yields a rate 50 times lower that the direct production, with equal contribution of signal and background. In the same spirit, CMS has investigated also the production of Higgs decaying in two photons in association with high E_t/E jets, which yield a signal to background ratio close to 1, the background being dominated by the bremsstrahlung contribution [2].
For Higgs masses above 100 GeV, a 5σ discovery limit can be reached combining both experiments after 3 years at low luminosity only, while for lower masses 1 year at high luminosity is required (Fig. 6).

1.2 Associated production $t\bar{t}H, WH,\ H \rightarrow b\bar{b}$

This channel is potentially quite powerful for Higgs search , since the branching ratio for Higgs to $b\bar{b}$ is almost 100% in that mass region. Two channels have been investigated by ATLAS [6]. The first one, WH, where the W decays semi-leptonically for trigger issues, has a resonant final state, since one reconstructs directly the H mass from 2 b-jets, although the mass spectrum is distorted due to hadronization processes. It thus requires b-jet tagging with ϵ_b= 50% for R_{jet} = 50-100, which seems reachable with the vertex detectors foreseen in ATLAS and CMS, and a jet veto to reject the $t\bar{t}$ background, limiting the use of this channel at low luminosity.

Moreover this channel is affected by the resonant WZ background, which could nevertheless be normalized by using leptonic decays of the two bosons (Fig. 4).

An other possibility is the $t\bar{t}H$ production, which yields 4 b-jets in the final state. One then requires at least 3 tagged jets, but one is left with a large $t\bar{t}$ background, and a large combinatorial background on the signal itself (Fig. 5), which means that the statistical significance obtained from this channel has to be used with some caution (Fig. 6).

Combining ATLAS and CMS and using the 3 different channels mentioned allows a discovery after 3 years of running at low luminosity, in the mass range from 80 to 130 GeV, even without taking into account the $t\bar{t}H$ channel, for the reasons mentioned above (Fig. 6).

2 130 GeV $\leq m_H \leq$ 800 GeV

2.1 $H \rightarrow ZZ^{(*)} \rightarrow l^+l^-l^+l^-$

This mode is the most promising in the mass range above the limit reachable by the $\gamma\gamma$ and $b\bar{b}$ decay modes, and below the ZZ mass threshold. The final state is clear and fully contained (4 leptons with p_T above 7-10 GeV with one pair of leptons peaking on the Z mass). The mass resolution is still of great importance below the ZZ mass threshold since the Higgs remains quite narrow. ATLAS shows comparable mass resolutions in the 4-electron and 4-muon mode (1.7 GeV for m_H=130 GeV). In the muon channel, both tracker and stand-alone measurements contribute equally. For CMS, the 4-electron mass resolution is worse than in ATLAS ($\simeq$ 2 GeV) due to the 4 Tesla field, while the muon measurement, dominated by the tracking measurement, is significantly better ($\simeq$ 1 GeV) [7, 8].
The irreducible background is the ZZ^*/γ^* continuum, while the reducible backgrounds are the $Zb\bar{b}$ and $t\bar{t}$, with 4 leptons in the final state, from which 2 are originating from b-decay. One can use this feature to reject these backgrounds, namely by applying isolation (at calorimeter or tracker level), since leptons from b's will be surrounded by hadronic activity. One has to apply in addition vertexing cuts (correlated to the isolation cuts), i.e. to cut on the normalized impact parameter of the final leptons to further reduce these backgrounds and bring them down to $\simeq$ 15% of the ZZ^*/γ^* continuum [7]. This rejection requires powerful vertex detectors as foreseen in ATLAS and CMS providing an asymptotic impact parameter resolution $\simeq$ 20 μm. As can be seen in Fig.7, a standard model Higgs can be discovered in the mass range 130-180 GeV after 3 years of running at low luminosity.

Above the ZZ mass threshold, the Higgs becomes broad, thus making the detector requirements less stringent. Moreover, one is left with the ZZ continuum background only, allowing a discovery up to 500 GeV at low luminosity [3, 9]. For higher masses, the Higgs width increases rapidly, and one will need the highest luminosity to be able to extend the search up to $\simeq$ 800 GeV (Fig. 8).

2.2 $H \rightarrow ZZ \rightarrow l^+l^-\nu\bar{\nu}$

For higher masses the signal becomes rapidly rate limited, so one can investigate the $H \rightarrow ZZ \rightarrow l^+l^-\nu\bar{\nu}$ decay mode, which provides six times more rate than the 4-lepton mode, at the expense of a non fully constrained final state. The dominant background, assuming that the calorimeter covers at least down to $|\eta| = 4$ in rapidity, is coming from the ZZ continuum contribution, for $E_t^{miss} \geq 200$ GeV (Fig. 9). Fake E_t^{miss} created by mismeasured jets is a potential source of background, and has been investigated by ATLAS showing that this contribution due to the crack region between the barrel and end-cap calorimeter is well under control (Fig. 9).

The final signal is broad, as the background, with a large uncertainty on the ZZ and WZ rates, making the final interpretation of the results difficult (Fig. 10).

3 $m_H \simeq 1$ TeV

In this mass region, one needs the higher rate possible, and one investigates hadronic final states, as in the process $H \to WW \to l\nu jj$, which provides 150 times more rate than the 4-lepton mode, or $H \to ZZ \to lljj$, 7 times smaller in rate than the WW mode. The signal reconstruction has to face the difficult issue of reconstructing 2 high-p_T jets from the W decay, nearby in space due to the boost of the W. The W reconstruction algorithm used starts first by searching for one hight p_T jet reconstructed in a given cone (ΔR $\simeq$ 0.5), and then looks for two seeds inside this cone with ΔR $\simeq$ 0.2. This procedure requires a good calorimeter granularity, as provided by ATLAS and CMS, to have a high reconstruction efficiency (around 50%), and a good jet energy resolution, allowing to use a narrow window $m_W \pm 15$ GeV) around the jet-jet mass, to reject the W+jet background.

An extra rejection against $t\bar{t}$ and W+jet backgrounds requires to veto on an extra central jet, and to require jets at small angle, called "tagged" jets and originating from the WW fusion process. These jets are emitted at large rapidity ($2 \leq |\eta| \leq 5$) and are strongly affected by the pile-up contribution at high luminosity, making necessary to apply a E_t cut on each cell of the forward/ backward calorimeter. The double tag efficiciency is found by ATLAS to be 23% for a background rejection of 150 at high luminosity.

Fig. 11 shows the signal and background mass distribution in CMS for the two decay modes mentioned. Clearly many years at high luminosity may be necessary to extract a signal, after a deep understanding of the background shape, and the tagging efficiency.

4 Strongly interacting Higgs

In the event that no Higgs is found below 1 TeV, one can look for an increase of the production of same-sign W pairs, due to the the scattering of longitudinally polarized W's, with respect to the Standard Model predictions. This deviation may be difficult to observe, even in the leptonic decay mode [1].

Some models like Technicolour try to restore the unitarity in gauge boson scattering by predicting the existence of $Z_L\gamma$ and Z_LW_L resonances. These resonances would be observable in the leptonic decay mode up to $\simeq$ 2 TeV [1].

An other non resonant SSB model (EChL approach) predicting an excess of events in the WZ mass spectrum with respect to the Standard Model predictions has also been investigated [2].

5 Conclusions

The two LHC detectors, ATLAS and CMS, exhibit similar potentials to search for a Standard Model Higgs, although based on different concepts and technologies. Most of the studies summarized here have been performed at a full simulation level, and most detector performance are assessed by test beam results of already large scale prototypes.

Both ATLAS and CMS are able to observe a Standard Model Higgs in the mass range 80-1000 GeV, in most cases after three years of running at low luminosity. These detectors allow to observe extra signals if no Higgs is found, and they allow to overlap with the area covered by LEP, leaving no region in the mass spectrum unexplored.

References

[1] ATLAS Technical Proposal, CERN/LHCC/94-43.

[2] CMS Technical Proposal, CERN/LHCC/94-38.

[3] D. Froidevaux et al., ATLAS Internal Note PHYS-048 (1995).

[4] C. Seez and J. Virdee, CMS Technical note TN/94-289 (1995).

[5] D. Froidevaux, F. Gianotti and E. Richter-Wąs, ATLAS Internal Note PHYS-064 (1995).

[6] D. Froidevaux and E. Richter-Wąs, ATLAS Internal Note PHYS-043 (1994).

[7] L. Poggioli, ATLAS Internal Note PHYS-066 (1995).

[8] A. Nikitenko, P. Verrecchia and D. Bomestar, CMS Technical note TN/95-019.

[9] D. Bomestar et al., CMS Technical note TN/95-018.

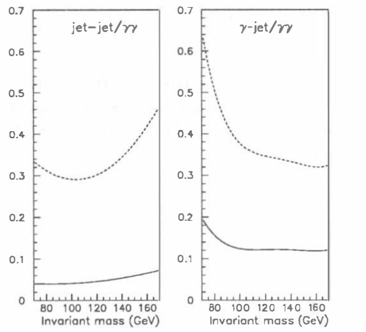

Figure 1: *ATLAS. $H \to \gamma\gamma$. Reducible background contribution before (dotted) and after (solid) isolated π^0 rejection.*

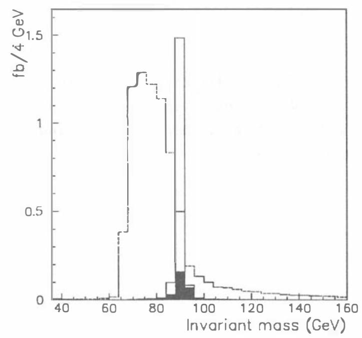

Figure 2: *ATLAS. $H \to \gamma\gamma$ issue when $m_H \simeq m_Z$. The radiative decay contribution (dashed), the Higgs signal (solid), and the $Z \to e^+e^-$ after track veto (black) are shown.*

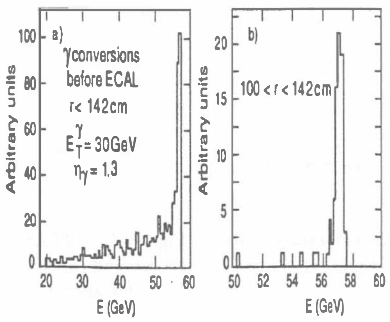

Figure 3: *CMS. Calorimeter response for converted photons at different conversion radii. Full simulation results*

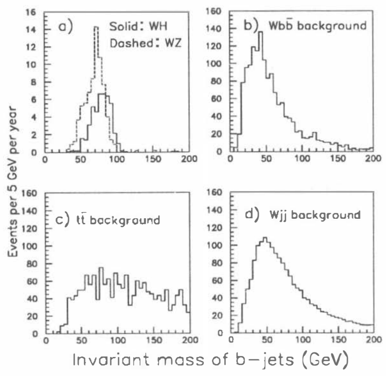

Figure 4: *ATLAS. Associated* WH *production, with* $H \to b\bar{b}$. *Signal (solid line in a)), resonant* WZ *background (dashed line in a)) and backgrounds (b) to d)).*

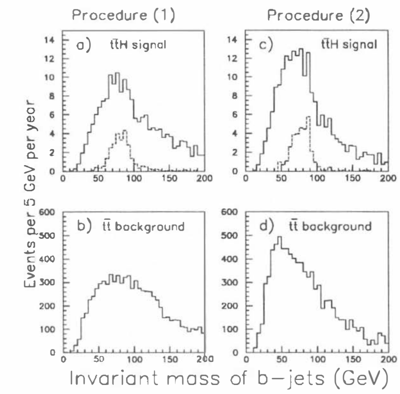

Figure 5: *ATLAS. Associated* $t\bar{t}H$ *production, with* $H \to b\bar{b}$. *Signal and backgrounds, including combinatorial background in the signal (solid lines in a) and c)).*

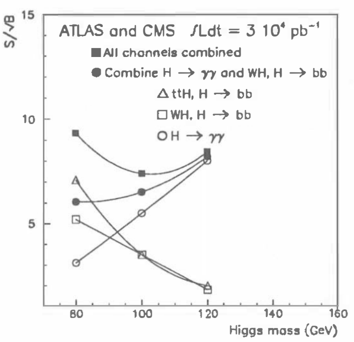

Figure 6: *ATLAS and CMS combined statistical significance for the low mass Higgs region, and for 3 decay modes (see text).*

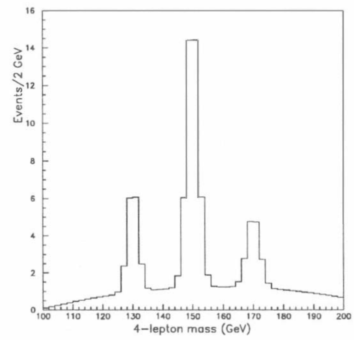

Figure 7: *ATLAS.* $H \to ZZ^* \to 4l$ *signal over background (after isolation and vertexing cuts) for 3 masses after 3 years at low luminosity.*

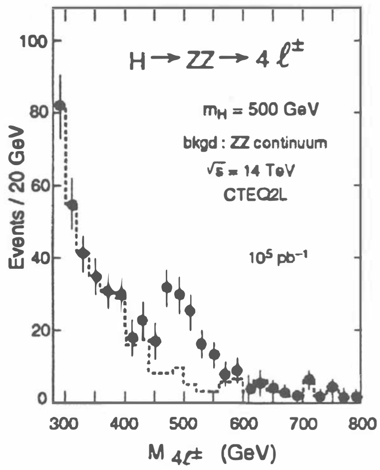

Figure 8: *CMS. $H \to ZZ \to llll$ signal over ZZ background, for m_H=500 GeV and 1 year at high luminosity.*

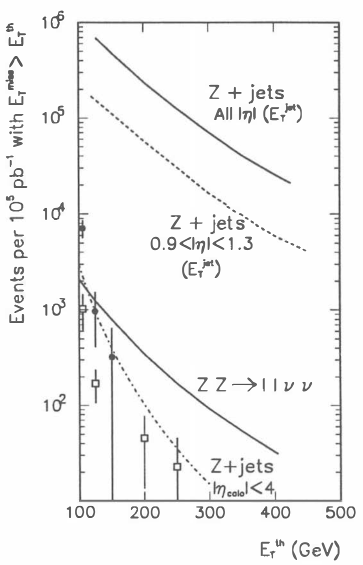

Figure 9: *ATLAS. Contribution to E_t^{miss} from Z+jets, and mismeasured jets in the crack region (points).*

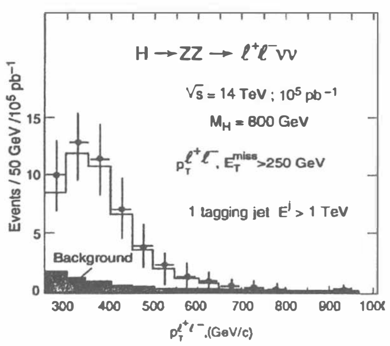

Figure 10: *CMS. $H \to ZZ \to ll\nu\nu$ signal and background, for m_H=800 GeV and 1 year at high luminosity.*

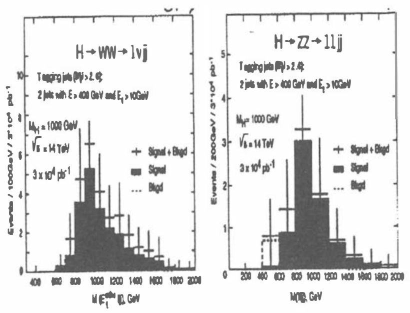

Figure 11: *CMS. $H \to WW \to l\nu jj$ and $H \to ZZ \to lljj$ signal and background for m_H=1 TeV, and 3 years at low luminosity.*