CAN ONE MISS A SM HIGGS IN THE INTERMEDIATE REGION?

M. Schneegans
Lapp / Annecy

ABSTRACT

The search for SM or MSSM Higgs bosons above Lep 180 reach should be one of the main tasks of the future colliders. In the intermediate mass region, and in particular in the range 80 - 130 GeV/c^2, only the 2γ decay mode of a Higgs produced inclusively or in association with a W, gives a good chance of observation. After a brief review of the signal and background rates recently recalculated for SSC and LHC, the possibilities of various calorimeters envisaged for these colliders are discussed. It appears that only a 'dedicated' very high resolution calorimeter with photon angle reconstruction and π^0 identification capabilities has a high probability to detect a SM Higgs signal over all the intermediate region.

1- Introduction

As is commonly agreed, a Standard Model Higgs boson should be seen at Lep 180, if its mass is lower than $\sim$ 80 GeV/c^2. If Lep is pushed to its ultimate energy, 90 GeV/c^2 may be reached.As was confirmed in this conference[1] and in the Aachen workshop[2], the reaction pp$\rightarrow$ZZ$\rightarrow$4l, with low rates but clean signature, should allow safe Higgs detection for masses between $2M_Z$ and $\sim$ 800 (1000) GeV/c^2 at LHC (SSC). In the intermediate mass region ($M_Z < M_H < 2M_Z$), the same process with at least one Z produced off-shell, should permit to be sensitive to masses down to $\sim$ 130 GeV/c^2, where the ZZ* production cross-section is falling off rapidly.

As shown in several studies of the ECFA working groups, only two processes stand a chance to reveal a Higgs for masses in the range 80 - 130 GeV/c^2:

$$pp \rightarrow H^0 (\rightarrow \gamma\gamma) + X \qquad (1)$$

and

$$pp \rightarrow H^0 (\rightarrow \gamma\gamma) + W (\rightarrow l\nu) + X \qquad (2)$$

Fig. 1 shows the bridging of the gap in the intermediate mass region which can be expected from these 2 channels. One or several neutral MSSM Higgs boson in the intermediate region could also give observable signals at LHC/SSC, in particular in the 2γ decay mode, but the coverage of all the parameter space seems difficult and has to be studied in detail[3].

The detection of channel (1) and (2) being particularly demanding on detectors, we will discuss in this talk the ability of various calorimeters proposed for LHC or SSC to observe them. Beforehand, we will briefly recall some of their features and rates. The standard luminosity conditions of 10^{33} cm^{-2}s^{-1} (10^4 pb^{-1}/year) for SSC and 10^{34} (10^5 pb^{-1}/year) for LHC will be used. At LHC, the pile-up of $\sim$ 10 events per bunch crossing (15ns) will cause several additionnal difficulties:
- particle identification by applying an isolation cone will be less efficient,
- the energy measurement of electromagnetic showers will be contaminated by particles from the same bunch crossing(s), hitting the same cells,
- there will be an ambiguity in the $\gamma\gamma$ vertex z-coordinate.

2- The $H^0 \rightarrow \gamma\gamma$ channel

This channel has been studied for a long time and recently recalculated for SSC[4] and LHC[5]. The cross-section for Higgs production in pp collisions [6], multiplied by the branching ratio into 2γ, yield 'comfortable' event rates ($\sim$ 3000 in a typical LHC year) up to $\sim$ 150 GeV/c^2. The width of the reconstructed mass peak will be completely dominated by the detector energy resolution, since the Higgs width in the considered mass region is smaller than 10 MeV.

The background for $H^0 \rightarrow \gamma\gamma$ is of 2 kinds:
- the 'irreducible background', which is the direct simulation of two photons by essentially 3 processes: $q\bar{q}$, gg and higher order diagrams (mainly bremsstrahlung). This background is very large (several hundreds of pb). Kinematical cuts allow to bring it down to $\sim$ 200 fb/GeV at LHC.
- a combination of gammas from π^0s inside jets. Many γ pairs are produced since the

cross-section for di-jets is $\sim 10^7$ times higher than for 2γ. A γ/jet discrimination of $\geq 10^4(\times 10^4)$ is needed to bring the combinatorial background an order of magnitude below the irreducible background, as necessary because of the large uncertainties in the estimates. The rejection, using an optimized isolation cone around each of the photons, works efficiently at $L \leq 10^{33}$ and reaches the desired level. But at 10^{34}, a further rejection by π^0 identification for transverse momenta up to ~ 50 GeV/c is needed, implying a 2-photon separation of better than 5 mrad.

The simulation conditions used in the two recent calculations are summarized in Table 1. The signal and background rates obtained in these conditions are plotted in Fig. 2 in terms of significance $S/\sqrt{B}$, for Higgs masses between 80 and 160 GeV/c^2. The rates are taken in a narrow mass window optimized for best significance and corresponding to 70-80% efficiency for the signal.

Table 1: $H^0 \to \gamma\gamma$ simulation conditions

	SSC/L*	LHC/ECFA
$\sqrt{S}$	40 TeV	16 TeV
Luminosity/Stat	$10^{33}/10^4$ pb^{-1}	$10^{34}/10^5$ pb^{-1}
Kinematical Cuts	$\lvert\eta_\gamma\rvert < 2.8$, $E_T > 20$ GeV $\lvert\eta_{\gamma\gamma}\rvert < 3$, $\cos\theta^* < 0.8$	$\lvert\eta\rvert < 2$, $P_{T_1} > 40$, $P_{T_2} > 25$ $P_{T_1}/(P_{T_1} + P_{T_2}) < 0.7$
Isolation Cut	Large CONE $R = \sqrt{\Delta\phi^2 + \Delta\eta^2} = 0.6$	Small CONE $\Delta\phi \times \Delta\eta = 0.1 \times 0.1$
Resolution (σ/E)	$2\%/\sqrt{E} \oplus 0.5\%$	$2\%/\sqrt{E} \oplus 0.5\%$
Pile-up	No	Smearing for 1 beam crossing and $\Delta\phi \times \Delta\eta = 0.1 \times 0.1$
Vertex	Precisely known	Reconstructed (σ = 1 cm)
π^0 identification	No	Yes (2γ separation ~ 5 mrad)
Simulation code	PYTHIA 5.4	ISAJET

With the luminosity conditions used, LHC rates should be somewhat larger than SSC rates, even taking into account losses due to pile-up and to some vertex smearing. But differences in the cross-sections used, in the backgrounds considered and in the kinematical cuts result in some excess for SSC rates. In any case, one can observe that signal rates are of the order of 500 - 1000 events at LHC as well as at SSC, and that their significance is well above 5, except for 80 GeV/c^2.

But these rates should not give us the feeling that observing a SM Higgs signal could be an easy task! The signal will sit on a 5 - 30 times higher background and uncertainties on rates are rather large. Moreover, an excellent calorimeter has been assumed with an energy resolution difficult to achieve. Fig. 3 illustrates what would be seen by such a detector and what a standard sampling calorimeter would see [4].

Another way to stress the importance of energy resolution is to express it in terms of running time needed to reach a significance of $\sim$ 5, for M_H =100 GeV/c^2 for instance: The conventionnal calorimeter will have to sum up data over more than one year ($\sim 10^5$ pb^{-1}), whereas the excellent one will need only $\sim$ 0.3 year ($\sim 3 \times 10^4$ pb^{-1}). Summing up data over more than 1 year increases the chances to smear the mass peak and to miss it! One can also remark that the excellent detector will reach the goal in $\sim$ 1 year at an average luminosity of 0.3×10^{34} cm^{-2}s^{-1}!

3- The ($W \to l\nu$)($H^0 \to \gamma\gamma$) channel

This channel is characterised by both small event and small background rates. Two processes contribute:

pp $\to W^* \to$ WH (or ZH to $\sim$ 20%), $W \to l\nu$, $H \to \gamma\gamma$ see ref 5

pp $\to t\bar{t}$ H, t (or $\bar{t}$) $\to$ Wb , $W \to l\nu$, $H \to \gamma\gamma$ see ref 7

Both processes result in the same signature: 1 high P_T lepton and 2 photons. The event rates for WH$\to l\gamma\gamma$, via W* or via $t\bar{t}$, as calculated by J.F.Gunion[7] for SSC and LHC, in the conditions given below for background rejection, are shown in Fig. 4. A total rate of about 50 events is expected in one LHC year, between 70 and 140 GeV/c^2.

The background is again of 2 kinds: 'irreducible' (W + 2γ) and reducible (simulation of l$\gamma\gamma$ by bb$\gamma\gamma$, bbγ, bbg, W + 2jets). After kinematical cuts + isolation cones + narrow mass window ($\sigma_E = 2\%/\sqrt{E} \oplus 0.5\%$), the background is reduced to a few events.

The uncertainties on signal and background rates are at present very large, coming from the choice of distribution functions, QCD corrections, additional loops, etc... If signal and background levels are confirmed, it may be possible to relax slightly the rejection criteria. This channel could represent a nice confirmation of a Higgs signal observed via channel (1) at SSC or LHC. It could also provide an overlap with Lep, since the rates seem usable down to 70 GeV/c^2.

4- Characteristics of the 'ideal' calorimeter

As was stressed in the Aachen workshop, to be confident not to miss the signals of a SM Higgs between $\sim$ 80 and $\sim$ 150 GeV/c^2, a calorimeter should have following characteristics:

- An excellent Energy resolution: it means very low a-term ($\leq$ 3%) and b-term ($\leq$ 0.5%). In fact, it was shown that going from 2 to 10% for the a-term causes a loss in significance similar to an increase from 0.5% to 1% of the b-term.

- A fine angular granularity: $\Delta\eta \times \Delta\Phi < 0.02 \times 0.02$ over a pseudorapidity range $\eta = \pm 2$ at least. In fact, an acceptance for $H^0 \to \gamma\gamma$ of $\eta = \pm 2$ is adequate but, since we also want to detect l$\gamma\gamma$ and 4e final states, an acceptance of $\eta = \pm$ 2.5 or 3.0 is desirable. The fine granularity implies a small Moliere radius and/or a large internal detector radius. It is very useful for position resolution and particle identification but is essential for precise energy measurement at LHC by minimizing the effects of pile-up.

- A photon angle reconstruction better than 10 mrad; it was shown that smearing the mass peak by the vertex uncertainty ($\sigma_z \sim 5.5$ cm) caused a loss in significance as large as the loss caused by poor E resolution. An uncertainty of $\sigma_z \leq 1$ cm causes an acceptable loss and allows in general to solve the vertex ambiguity and thus to use the precise value known from charged particles. Moreover, the 2γ combinatorial background will be greatly reduced by associating both photons to the same vertex.

- A good 2-photon separation for identification of π^0s with tranverse momenta up to $\sim$ 50 GeV/c. This means a 2γ separation down to $\sim$ 5 mrad which can in general not be obtained in the calorimeter itself.

- A fast readout: the energy smearing due to pile-up of events depends on the effective integration time. Integration over a single bunch crossing is highly desirable for an optimum detector.

- Radiation hard materials are of course mandatory particularly at the largest rapidities considered. The energy response should not be affected (by more than a few percent) by photon levels of $\sim$ 10 Mrad/year.

5- Possibilities of some of the proposed calorimeters

To illustrate the possibilities of various electromagnetic calorimeters for detecting a Higgs signal in the intermediate region, let us take a sample of detectors which are being studied for SSC or LHC and compare their aptitude for 2-photon detection.

We first consider two high-performance sampling calorimeters envisaged for LHC: a scintillating fiber/lead detector[8] (SPACAL) and the 'Accordion' Liquid Argon/iron detector[9] (LAr). We also consider four homogeneous calorimeters: a BaF_2 crystal calorimeter [4] (BaF_2) and a Liquid Xenon calorimeter[4] (LXe/SSC) for SSC, a Liquid Xenon calorimeter[10] (LXe/LHC) and a crystal calorimeter [11] (CRYSTAL) for LHC.

Since descriptions of these detectors can be found in litterature, they will be considered as known. Their main characteristics relevant to 2γ detection are listed in Table 2, where the quoted figures are preliminary measurements, Monte-Carlo estimates or just goals. No firm conclusions on the detector performance should be drawn at this stage.

Taking some of these characterisics, we can make following comments:

- Energy resolution: The a-term of an homogeneous calorimeter is usually low ($1-3\%$). For good scintillators, contributions like photostatistics or electronic noise are negligible above 10 GeV and the a-term only reflects the slow variation of the 'constant' b-term. For a excellent sampling calorimeter, one can hope for an a-term of 8-10%. Thus, a 'dedicated' calorimeter should clearly be made of an homogeneous detection material.
It is very difficult for any calorimeter to bring the b-term down to $\sim$ 0.5%. This can only be achieved if a high priority is given to E resolution at all levels: choice of design parameters, details of construction, methods and frequency of tower calibration and monitoring (besides physics processes).Note that here, a low a-term helps allowing good use of Sources, Cosmics, MIPs, LEDs, RFQs, etc... On the other hand, If many compromises with other detectors and constraints have to be made, which is usually the case inside large multipurpose experiments, the b-term will not be very small.

Table 2: Parameters relevant to photon detection for several calorimeter projects (m=measured, h=hoped)

Project	SPACAL	LAr	BaF_2	LXe	LXe	CRYSTAL
Collider	LHC	LHC	SSC	SSC	LHC	LHC
	sampling		homogeneous			
X_0/R_M	0.75/$\sim$ 2.	2.0/$\sim$ 4.5	2.04/4.4	2.8 / 5.6		1.6/2.6 (CeF_3)
L (Xo/cm)	30/25	25/50	25/50	$> 22/> 60$	28/78	26/42 (CeF_3)
Cylinder R (cm)	150	$\sim$ 130	80	80	100	80 (CeF_3)
E resolution a $\sqrt{E}$(%) b (%)	 12.4 m 1.3 m/$\sim$ 1 h	 10.1 m/$\sim$ 8 h < 1. m/< 1 h	 2 h $\sim$ 0.5 h	 < 2 h $\sim$ 0.5 h	 < 1 h $\sim$ 0.5 h	 2 h $\sim$ 0.5 h
Calib. meth.	?	Electr. only	RFQ/MIP	α 5.5 MeV	?	MIP/RFQ?
Tower calib.	?	No	Frequent	Frequent	?	Frequent
Granularity $\Delta\eta \times \Delta\phi$	not yet defined	$\sim 0.02^2$	0.04^2	0.045^2	0.03^2	0.02^2
Segmentation	No	in 2 or 3	No	in 3	in 14	in 2
Pos. resol. σ X,Y (mm) (> 10GeV)	m $\sim$ 2. (5cm cell)	m X:4.4$\sqrt{E}$ Y: 700μm	h $\sim$ 1	h $\sim$ 1.5	h 0.1	h 0.5
γ angle (mrad)	No	Yes $\sim$ 7	No	Yes 10-15	Yes $\sim$ 1 !	Yes 5-10
π^0 ident.	Cell size ?	Posit. det.?	Cell size		< 1mrad ?	Posit. det.

An homogeneous 'dedicated' calorimeter stands the best chances to reach both low a-term and b-term.

- Granularity and segmentation: Most LHC detectors aim at $\Delta\eta \times \Delta\Phi \sim 0.02 \times 0.02$ (LXe at 0.03×0.03). The two SSC detectors aim at 0.04×0.04, which may be adequate below 10^{33}. LHC detectors foresee segmentation, except SPACAL.

- Position and angle resolution: Position resolution is in general related to cell size. All detectors aim at $\sigma_{x,y} \leq 1$ mm for E$\geq$ 50 GeV (LXe/LHC claims 0.1 mm). Photon angle implies segmentation and good position resolution. The expected angular resolution looks adequate (5-10 mrad) for LAr and CRYSTAL and very good for LXe/LHC ($\sim$ 1 mrad). But, this information seems difficult to obtain for SPACAL calorimeter.

- π^0 identification: LXe/LHC claims an intrinsic 2γ separation of $\leq$ 1 mrad! LAr studies position detectors with 1.5 X_0 Pb converter, CRYSTAL studies a position detector between the 2 crystal segments, SPACAL has no plans for π^0 identification (?)

- Readout speed and Energy trigger: These are crucial aspects for a high performance calorimeter but the studies are not advanced enough to quote and compare parameters.

To summarize these remarks, we can say:
At LHC, a good fast sampling calorimeter, with photon angle reconstruction and π^0

identification capability (like hopefully LAr) stands a fair chance to detect a 2γ signal of a SM Higgs for masses between $\sim$ 100 and 150 GeV/c^2.
A fast 'dedicated' detector, with photon angle reconstruction, π^0 identification capability and very high resolution (low a and b terms) should not miss the 2γ signal of a SM Higgs between $\sim$ 80 and 150 GeV/c^2.
At SSC, the conditions being somewhat 'easier', a fast very high resolution detector, such as BaF_2 or LXe, should not miss a 2γ signal from a Higgs between 80 and 150 GeV/c^2.
On the other hand, if signal and background rates for the WH($\rightarrow l\gamma\gamma$) are confirmed, it may be possible to see such a signal at SSC and LHC, even with a slightly relaxed E resolution.

6- Conclusion

In the present state of signal and background calculations for $H^0 \rightarrow \gamma\gamma$ and WH$\rightarrow e\gamma\gamma$, it appears that the detection of a SM Higgs boson is indeed possible over all the intermediate region at SSC and LHC. A classical calorimeter inside a multipurpose apparatus has some chance to see such a signal, but could also miss it, in particular for masses below 100 GeV/c^2. A 'dedicated' very high resolution calorimeter, optimized for photon detection, should not miss a SM Higgs signal and would be in best position to explore the intermediate region for possible MSSM neutral Higgs bosons.

References:

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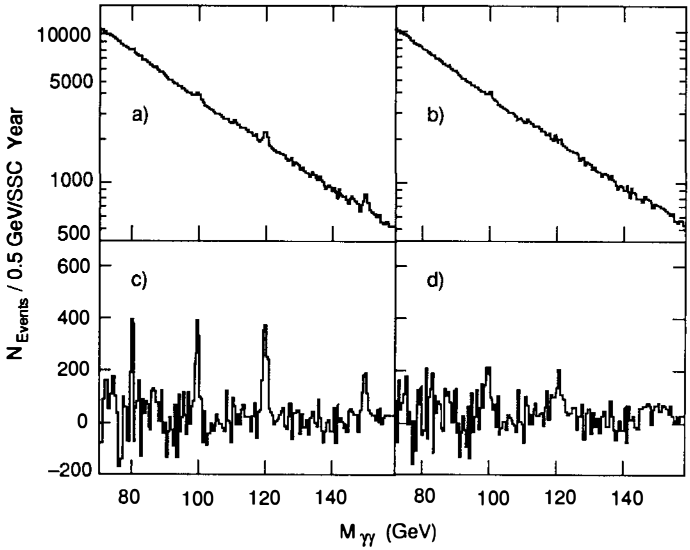

Fig. 3: $H^0 \rightarrow \gamma\gamma$ signal superposed on background for an excellent (3a) calorimeter ($2\%/\sqrt{E} \oplus 0.5\%$) and for a conventionnal (3b) detector ($15\%/\sqrt{E} \oplus 1\%$). Fig. 3c and 3d show corresponding pictures after background substraction.

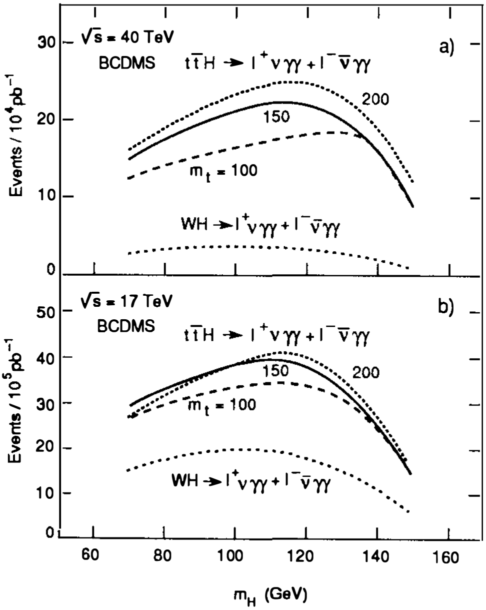

Fig. 4: Rates for WH production via W^* and $t\bar{t}$ calculated by J.F. Gunion for SSC a) and LHC b) after cuts.

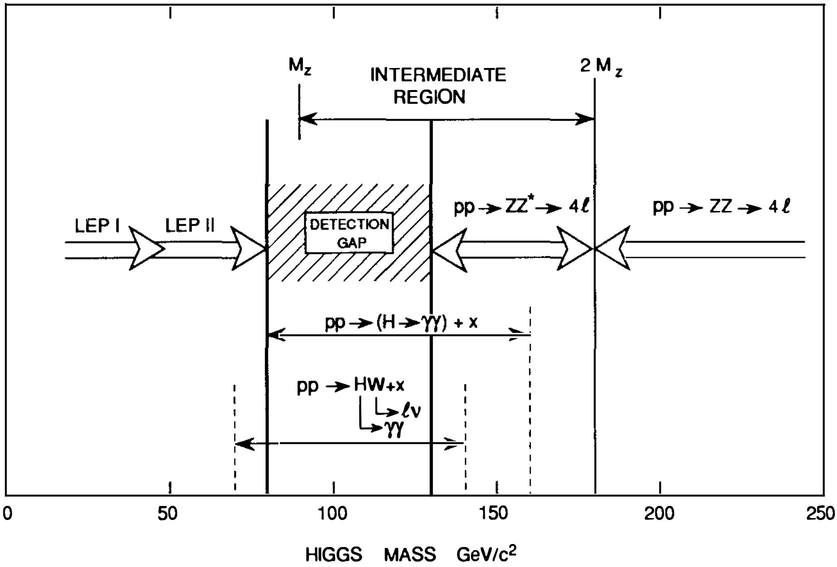

Fig. 1: Higgs detection in the intermediate mass region and bridging of the detection gap: 80–130 GeV/c^2 by the 2 γ and ℓ 2γ modes.

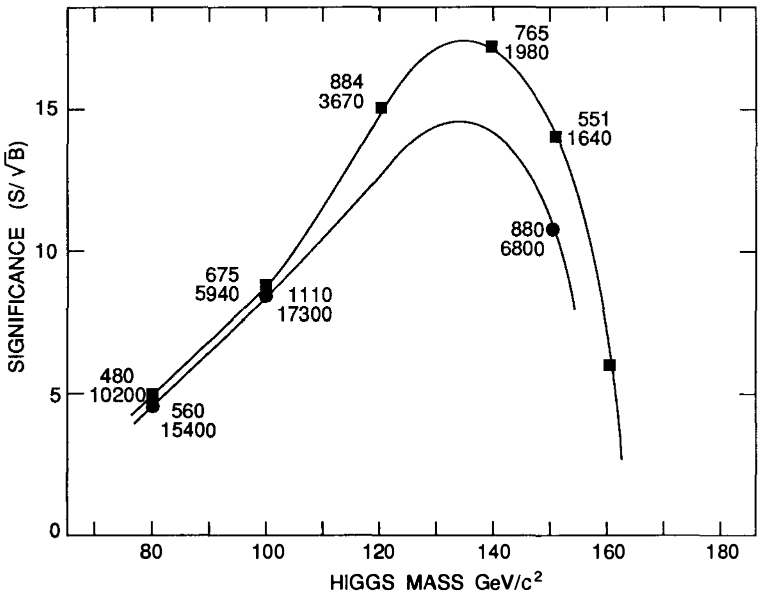

Fig. 2: Significance and rates for $H^0 \rightarrow \gamma\gamma$. Black squares are for 10^4 pb^{-1} collected at SSC and black circles for 10^5 pb^{-1} at LHC.
Top numbers are signal rates, bottom numbers are background rates.