ISTITUTO NAZIONALE DI FISICA NUCLEARE - ISTITUTO NAZIONALE DI FISICA NUCLEARE - ISTITUTO NAZIONALE DI FISICA NUCLEARE - ISTITUTO NAZIONALE DI FISICA NUCLEARE - ISTITUTO NAZIONALE DI FISICA NUCLEARE - ISTITUTO NAZIONALE DI

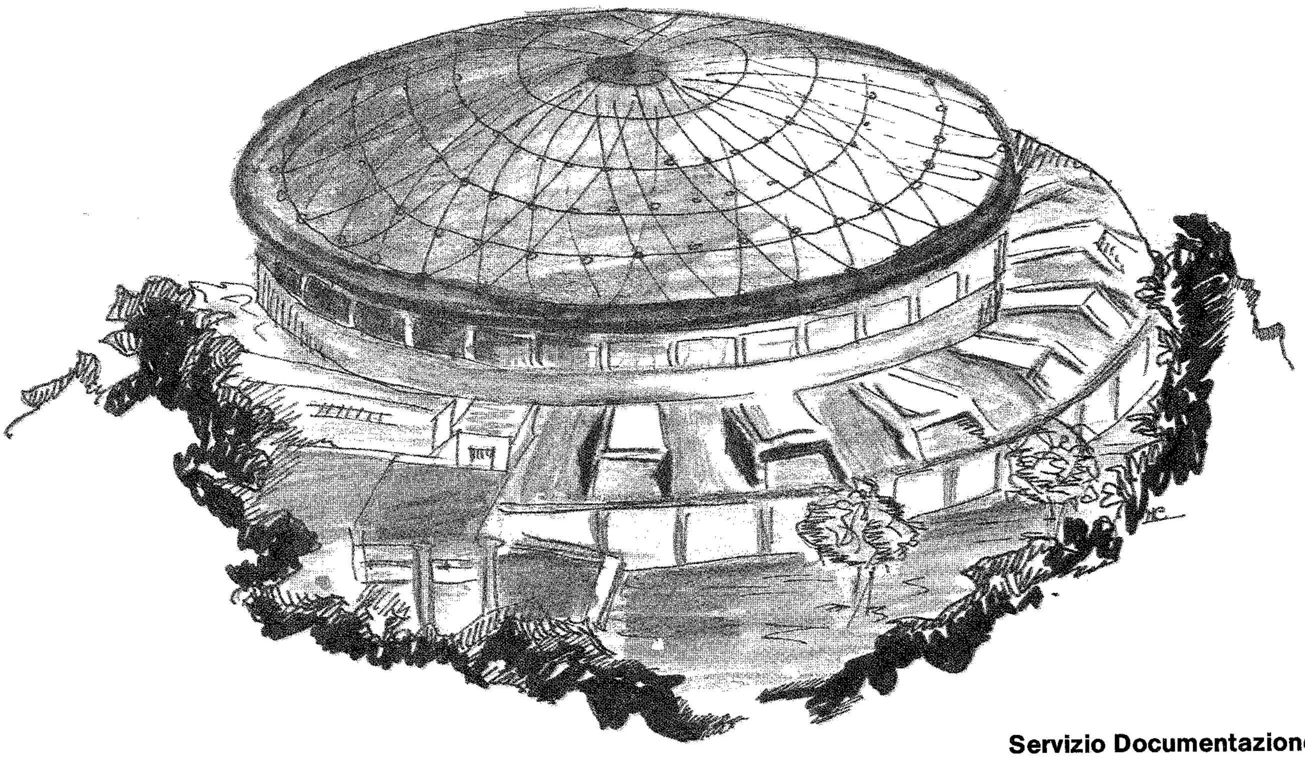
Laboratori Nazionali di Frascati

LNF-90/085(PT)
5 Dicembre 1990

A. Grau, T. Han, G. Pancheri:

$HZ \to \gamma\gamma l^+ l^-$: A POSSIBILITY FOR AN EXTREMELY HIGH LUMINOSITY COLLIDER

Contribution to Workshop on ECFA/LHC
Aachen 4-9 October, 1990



Servizio Documentazione
dei Laboratori Nazionali di Frascati
P.O. Box, 13 - 00044 Frascati (Italy)

INFN - Laboratori Nazionali di Frascati
Servizio Documentazione

LNF-90/085(PT)
5 Dicembre 1990

$HZ \rightarrow \gamma\gamma l^+l^-$: A Possibility for an Extremely High Luminosity Collider

A.Grau
Universitat Autònoma de Barcelona, Grup de Física Teòrica, 08193 Bellaterra, Spain

T.Han
Fermi National Accelerator Laboratory, P.O.Box, Batavia, Il 60510,USA,

G.Pancheri
INFN, Laboratori Nazionali di Frascati, P.O.Box 13, 00044 Frascati
and
Physics Department, University of Palermo, Palermo,Italy

Abstract

We have considered associated Higgs-Z^0 production at the LHC and calculated the intrinsic background to the signal $HZ \rightarrow \gamma\gamma l^+l^-$. Transverse momentum and invariant mass distributions for double bremsstrahlung from the initial quark legs are presented. It is shown that this background is well below the signal provided a very good mass resolution is obtained. Under normal luminosity conditions, the number of events is not sufficient for discovery, but it can be adequate if an extremely high luminosity is made available, i.e. L=5x$10^{34} cm^{-2} sec^{-1}$.

In this contribution to the Workshop we address the question of the Higgs search in the light intermediate mass region. For an Intermediate mass Higgs, i.e. one for which $m_Z \leq M_H \leq 2m_W$, there are two mechanisms which have been proposed [1] and which have been the object of extensive study in this workshop[2], i.e. direct Higgs production and decay into virtual Z^0 pairs[3] and $\gamma\gamma$ pairs[4]. For a Higgs boson of mass $M_H \approx m_Z$, the first of these mechanisms however cannot be used for lack of rate and therefore one must rely on the second and on the possibility of building a specialized detector with very high demands on resolution in order to overcome both the background from jets as well as the irreducible intrinsic background from $q\bar{q} \to \gamma\gamma$. On the other hand, this mass region is probably out of reach by LEP200 and may have to be explored by the Hadron Colliders. Indeed, to exclude or to confirm the existence of a Higgs boson degenerate in mass with the Z^0 is very important from a theoretical point of view. In this note we examine another signature, which is low in rate, but potentially very clean, i.e. associated Higgs-Z^0 production. The probability of finding a Higgs into a Z^0 at the LHC is $10^{-4} \div 10^{-5}$, a not impossibly small number . However, in order to overcome the intrinsic background from Z^0-pair production, one needs to search for Higgs boson decay modes inaccessible to the Z^0, i.e. $H\gamma\gamma$, because of Yang's theorem [5]. In addition, if one requires to observe only leptonic decay modes for the associated Z^0, the event rate becomes very low.

Since the event rate is marginal, special care must be taken to calculate the branching fractions, which become sensitive to virtual and rare channels, as well as to QCD corrections to the b-quark mass [6,7,8]. The decay rate into virtual Z^0's can be written as [9,10]

$$\Gamma(H^0 \to 4\mu) = \int_0^{m_H^2} dQ_1^2 \int_0^{(m_H-Q_1)^2} dQ_2^2 \Gamma(H \to Z^*Z^*) \cdot$$

$$\cdot \frac{Q_1 \Gamma(Z^* \to \mu^+\mu^-)}{\pi\left[(Q_1^2 - m_Z^2)^2 + (m_Z\Gamma_Z^*)^2\right]} \frac{Q_2 \Gamma(Z^* \to \mu^+\mu^-)}{\pi\left[(Q_2^2 - m_Z^2)^2 + (m_Z\Gamma_Z^*)^2\right]} \tag{1}$$

where Γ_Z^* is the total width of a Z_0 of mass Q and $\Gamma(H \to Z^*Z^*)$ represents the decay of the Higgs boson into a pair of Z_0's of masses Q_1 and Q_2 and it is given by

$$\Gamma(H \to Z^*Z^*) = \frac{G_F m_H^3}{16\pi\sqrt{2}} \sqrt{1 + \lambda_1^2 + \lambda_2^2 - 2\lambda_1\lambda_2 - 2\lambda_1 - 2\lambda_2}$$

$$\cdot \left[1 + \lambda_1^2 + \lambda_2^2 + 10\lambda_1\lambda_2 - 2\lambda_1 - 2\lambda_2\right]$$

with $\lambda_i = \frac{Q_i^2}{m_H^2}$. It can easily be checked that the above equation reproduces the known expression for $H^0 \to Z^0Z^0$ when $Q_1 = Q_2 = m_Z$.

In **Fig.1** we show the width of the Higgs boson calculated from eq.(1). Using parton densities from EHLQ, set II, [11], we obtain the values shown in **Fig.2** for the number of events at LHC and SSC, assuming a nominal integrated LHC luminosity $L = 10^5 pb^{-1}$ for LHC and $L = 10^4 pb^{-1}$ for SSC. The numbers shown are relative to a single lepton channel for Z^0 decay and nothing more than a rapidty cut , $|y_{H,Z}| \leq 2.5$. To see if the very high luminosity option which may be available at the LHC could make this process a viable one, one must study the intrinsic background from $Z\gamma\gamma$ and impose realistic cuts. We show

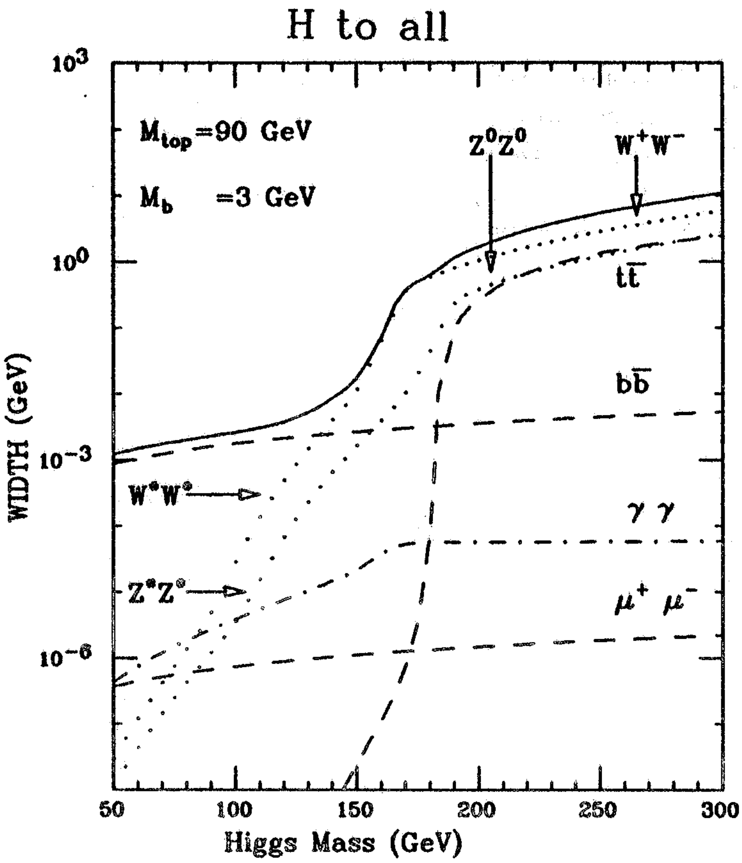
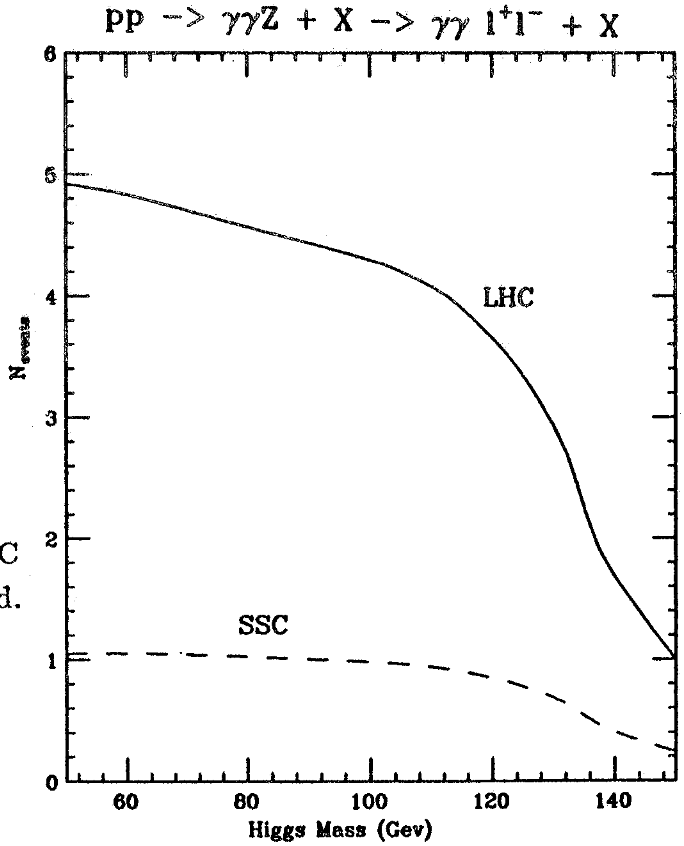


Fig.1 Decay width for an intermediate mass Higgs boson decaying into: W^+W^- and Z^0Z^0 pairs *on* and *off* the mass shell (dots), $t\bar{t}$ pairs (dashes), $b\bar{b}$ pairs (dashes), $\gamma\gamma$ pairs (dot-dashes), and $\mu^+\mu^-$ pairs (dashes). The values of m_{top}= 90 GeV and m_b= 3 GeV have been used. Full line is the total width.



ig.2 Number of events at LHC and SSC. An integrated luminosity L=$10^5 pb^{-1}$ for LHC and L=$10^4 pb^{-1}$ for SSC has been assumed.

in **Figs.3a** and **b** the invariant mass distribution of *gamma* pairs produced through QED bremsstrahlung from the initial quark legs annihilating into a Z^0, [12] together with the signal from $HZ \rightarrow \gamma\gamma Z$, within a 5 GeV bin. We have chosen two different cuts on the photons transverse momentum, so as to eventually improve statistics. In both cases, the signal is well visible above the background. Clearly, better mass resolution

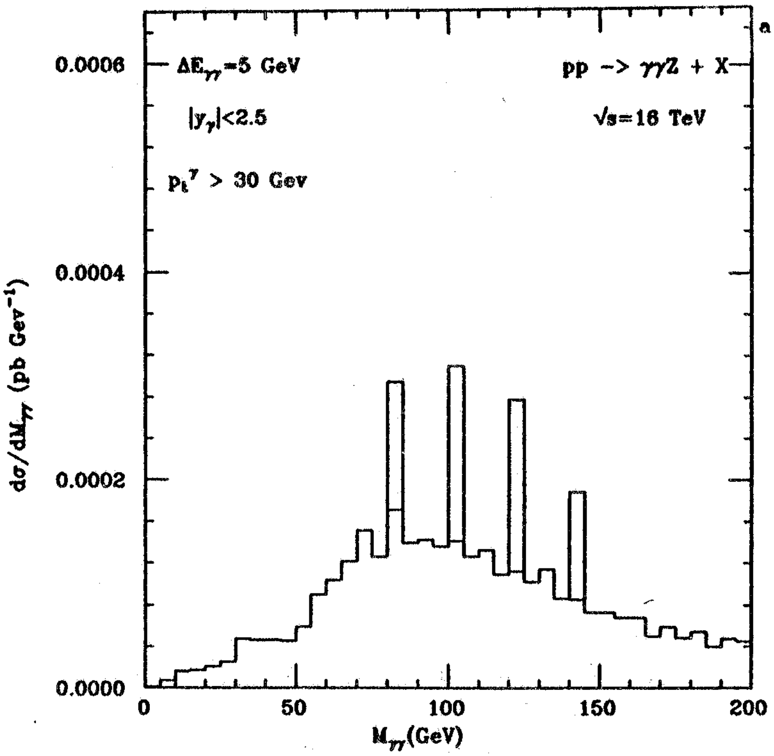


Fig.3a Differential cross-section for $pp \rightarrow Z\gamma\gamma + X$ vs. the invariant mass of the $\gamma\gamma$ system at $\sqrt{s} = 16\ TeV$. The signal has been added to the QED background for $M_{Higgs} = 80, 100, 120, 140\ GeV$ assuming a resolution $\Delta M = 5\ GeV$. The cuts $p_t^\gamma \geq 30\ GeV$ and $|y_\gamma| \leq 2.5$ have been imposed.

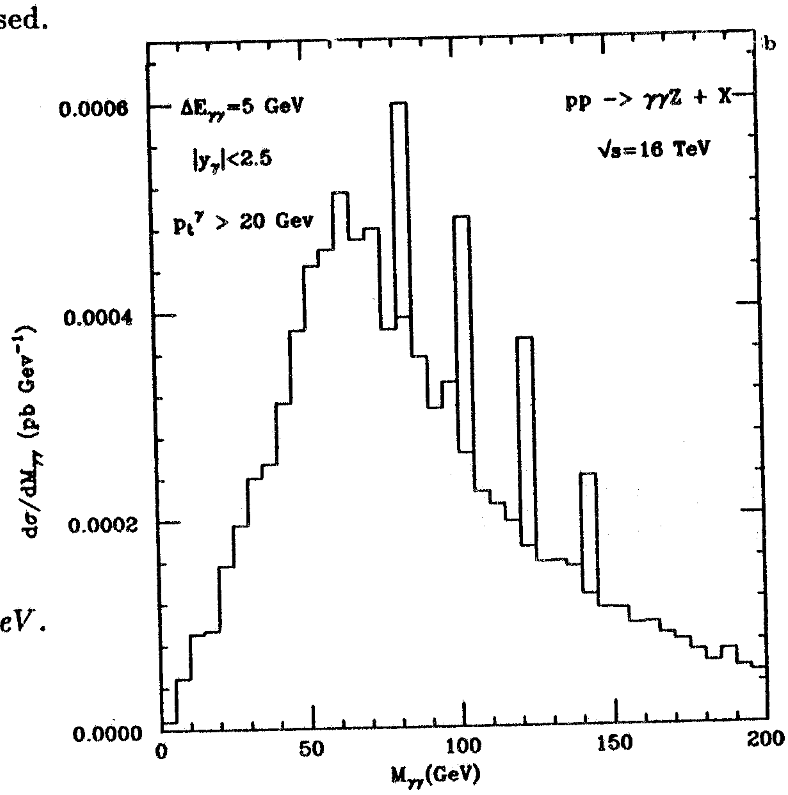


Fig.3b Same as **Fig.3a** for $p_t^\gamma \geq 20\ GeV$.

will further sharpen the signal. We show also in **Fig.4** the p_t distribution of the signal compared to the QED background for a cut of 30 GeV on the transverse momentum of the photons. One should also mention that in order to make use of this signal, the detector requirements must be very severe, in order to eliminate, among other things, the dangerous background from $Z + jet + jet$, with the jets faking an isolated photon. If this can be done, then from the intrinsic background analysis, it appears that the signal we have considered here may provide an unmistakable signature, provided the event rate is adequate. Under normal luminosity conditions, this is not the case. If however, the extremely high luminosity option, L=5x10$^{34}cm^{-2}sec^{-1}$ is available, then the number of events increases and this channel can become a viable one for investigation of a Higgs boson of mass 80 $GeV \leq M_H \leq 130$ GeV.

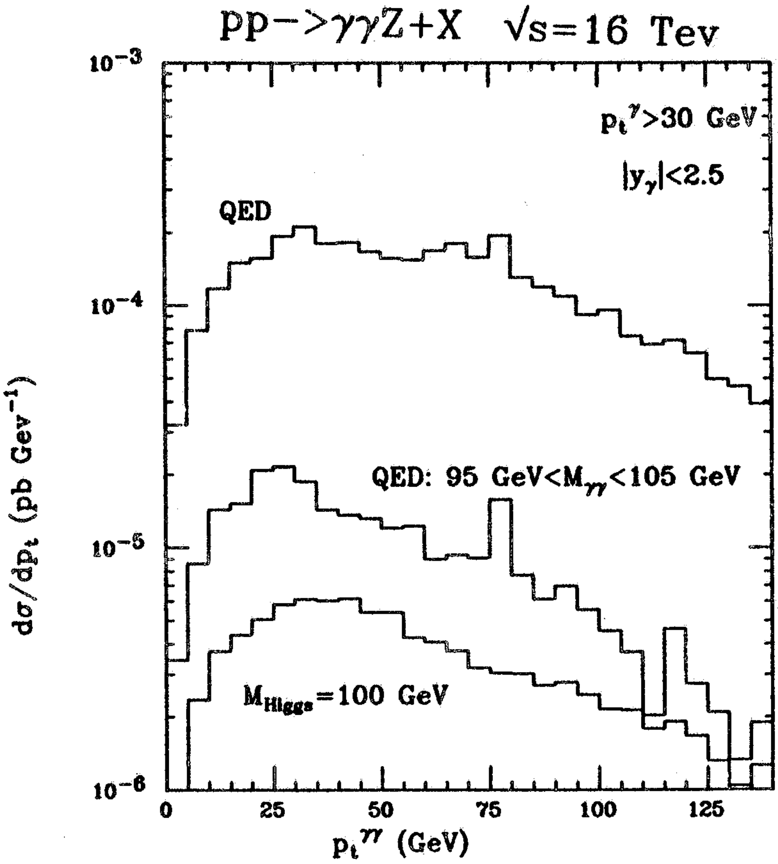


Fig.4 Differential cross-section for $pp \to Z\gamma\gamma + X$ vs. the p_t of the $\gamma\gamma$ system at $\sqrt{s} =$ 16 TeV. Histograms are for the purely QED process, i.e. Z^0 production and double bremsstrahlung from initial quark legs , and for production of a Higgs boson of mass $M_{Higgs} = 100$ GeV for a cut on the transverse momentum of the photons $p_t^\gamma \geq 30$ GeV and a rapidity cut $|y_\gamma| \leq 2.5$.

References

1. C.Rubbia, "Perspectives for a Hadron Collider in the LEP Tunnel", CERN Seminar, November 6th, 1989.
2. Z.Kunszt and J.Stirling, these Proceedings.
3. M.Della Negra et al., these Proceedings.
4. C.Seez, these Proceedings.
5. C.N.Yang, Phys.Rev. D77, 242(1950).
6. Z.Kunszt, Nuclear Physics B247, 339 (1984).
7. M.Drees and K.Hikasa, Phys. Lett. B240, 455 (1990).
8. S.C.Gorishny, A.L.Kataev, S.A.Larin and L.R.Surguladze, "Corrected three loop QCD correction to the correlator of the quark scalar currents and $\Gamma^{tot}(H^0 \rightarrow hadrons)$", TIFR/th/90-9, Feb. 1990.
9. R.Cahn, Reports on Progr. in Physics 52, 389 (1989).
10. A.Grau, G.Pancheri and R.J.N.Phillips, "Contribution of Off-shell-top-quarks to Decay Processes", LNF-90/020, March 1990. To appear in Physics Letters.
11. E.Eichten, I.Hinchcliffe, K.Lane and C.Quigg, Rev. of Modern Phys. 56 (1984) 579
12. V.Barger, T.Han and R.J.N.Phillips, Phys. ReV D39,146 (1989).