A flavour-independent Higgs boson search in e+e- collisions at √s up to 209 GeV

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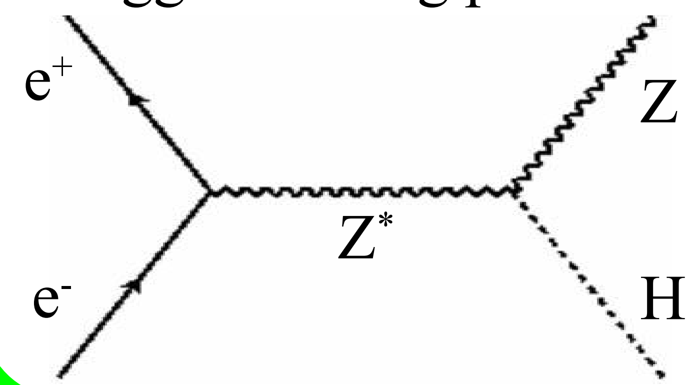
Introduction

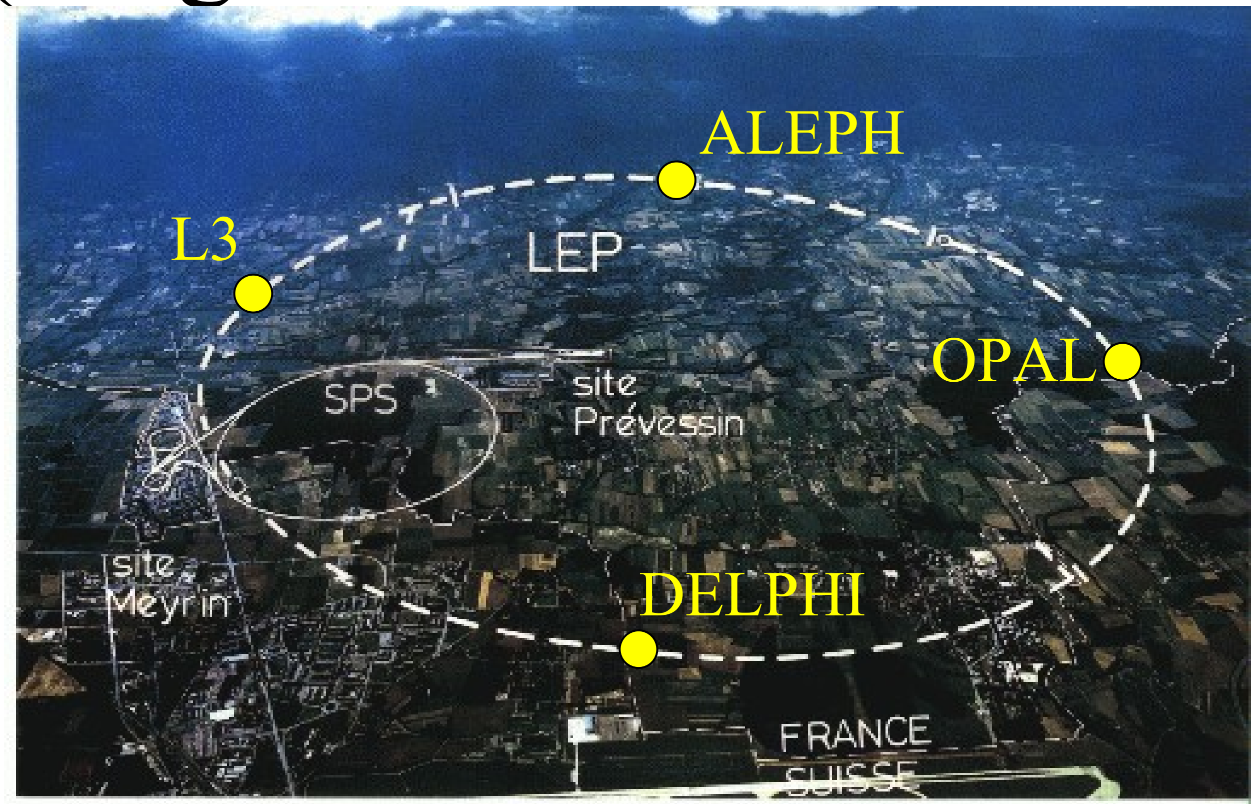
- Search for the Higgsstrahlung process ($e^+e^- \rightarrow ZH$)
- ALEPH experiment @ LEP
  - year : 1998~2000
  - centre-of-mass energy : 189~209 GeV
  - luminosity : 630 pb^{-1}

Year	Luminosity (pb^{-1})	Energy range (GeV)	$\langle\sqrt{s}\rangle$ (GeV)
2000	11.2	207–209	208.0
	122.6	206–207	206.6
	80.0	204–206	205.2
1999	45.2	–	201.6
	86.3	–	199.5
	79.9	–	195.5
	28.9	–	191.6
1998	176.2	–	188.6

Higgsstrahlung process

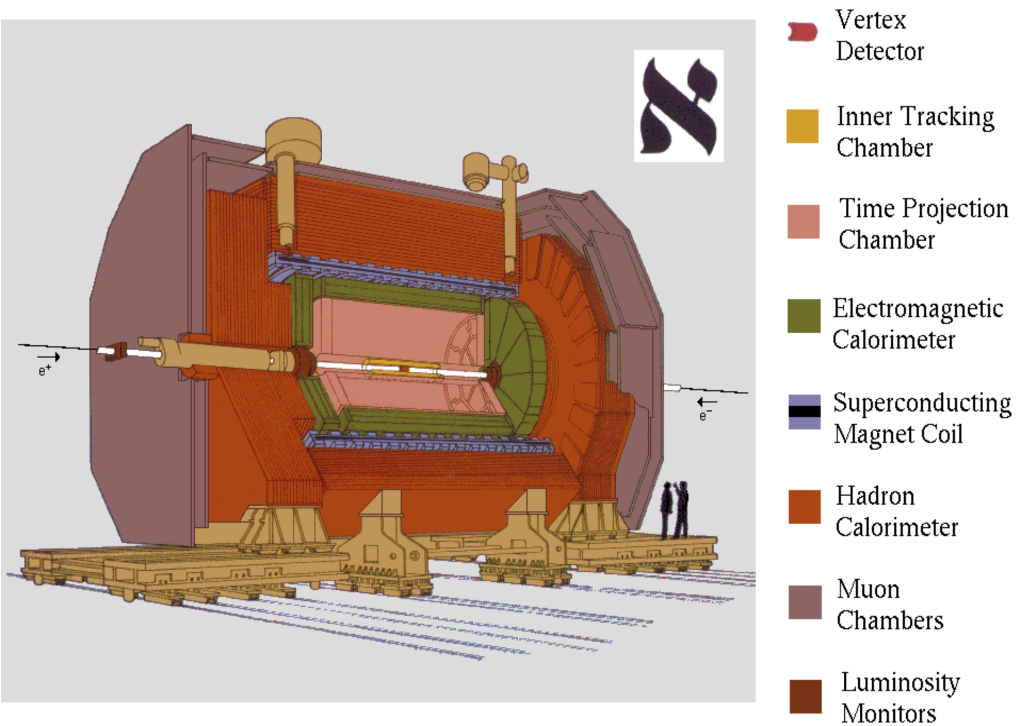


LEP(Large Electron Positron Collider)



- operated from 1989 to 2000
  - LEP1(1989~1995) : $\sqrt{s}$~91GeV to search Z boson
  - LEP2(1996~2000) : up to $\sqrt{s}$~209GeV

ALEPH detector



The ALEPH Detector

- Tracking
  - silicon vertex detector
  - drift chamber
  - time projection chamber
  - superconducting solenoidal coil (1.5T)

  $\rightarrow \delta p_t/p_t = 6 \times 10^{-4} p_t \oplus 5 \times 10^{-3}$ (p_t : GeV/c)

- Particle identification (e,γ)
  - electromagnetic calorimeter

  $\rightarrow \delta E/E = 0.18/\sqrt{E} + 0.009$ (E : GeV)

- Particle identification (μ)
  - hadron calorimeter
  - muon filter

  $\rightarrow \sigma(E) = 0.6\sqrt{E} + 0.6$ (E : GeV)

Events(observed, expected)

- The lepton pair final state
  - $H \to qq$, $Z \to ll$
- The missing energy final state
  - $H \to qq$, $Z \to \nu\nu$
- The tau lepton final state
  - $H \to \tau\tau$, $Z \to qq$
- The four-jet final state
  - $H \to qq$, $Z \to qq$

- Simulated event sample
  - signal
    - m_H from 40 to 115 GeV/c^2 in steps of 5 GeV/c^2
  - background
    - ZZ (including Zee, $Z\nu\nu$)
    - WW (including $We\nu$)
    - ff (including $\gamma\gamma \to ff$)

The lepton pair final state

- $H \rightarrow qq$, $Z \rightarrow ll$
- cross section : 6.7% (Higgsstrahlung)
- invariant mass of two leptons close to Z boson mass
- recoil mass equal to Higgs boson mass
- Higgs boson mass can be reconstructed with good resolution

Preselection

- find lepton pairs
  - identified or isolated oppositely charged particles
  - e-e or μ-μ pair
  - invariant mass of leptons : Z boson mass

background rejection

- $WW \to qql\nu$
  - $m^{hadr} + m^{lept} > 150$ GeV & $m^{hadr} - m^{lept} < 20$ GeV
    - $W \to l\nu$: identified lepton + missing four-momentum
    - $W \to qq$: the remaining energy flow particles
- $Z\gamma^*(\gamma^* \to ll)$
  - $m^{ll} + m^{recoil} > 115$ GeV
- $ll\gamma\gamma$
  - at least one charged particle in both jets
- $ee \to qq$
  - $P_t^{ll} > 20$ GeV
- reoptimise the requirement of Z mass ($m^{ll} > 77.0 \sim 82.75$ GeV)

Result

- 70 events are observed
  - 73.4 events expected from the SM backgrounds
- The signal efficiencies
  - $H \to bb, cc, gg$: about 80%
- discriminant variable in C.L. calculation
  - the reconstructed Higgs mass (recoil mass)

The missing energy final state

- H→qq, Z→νν
- cross section : 20% (Higgsstrahlung)
- missing mass consistent with Z boson mass

Preselection

- hadronic events having 5 or more reconstructed charged particles
- E_{tot} from all charged particles > 10%$\sqrt{s}$
- rejection of $\gamma\gamma$ process
    - $E_{30°}$ > 25%$\sqrt{s}$ or missing P_T > 5%$\sqrt{s}$
    - |missing P_z| < 50 GeV and missing mass > 50 GeV

→ ee→WW, ee→qq become the main background

The three-neural-network analysis

- NN1 (output : anti-qq)
  - 7 input variables (missing mass, $\theta_{missing\ p}$, missing P_T, $f_{30°}$, f_{wedge}, $\Delta\varphi$, s'/s)
  - training : signal, qq
- NN2 (output : anti-WW)
  - 3 input variables (missing mass, A, missing p)
  - training : signal, WW
- NN3
  - 4? input variables (anti-qq, anti-WW, two b-tag NN outputs?)
  - training : qq, WW, Weν, Zee, ZZ

Result

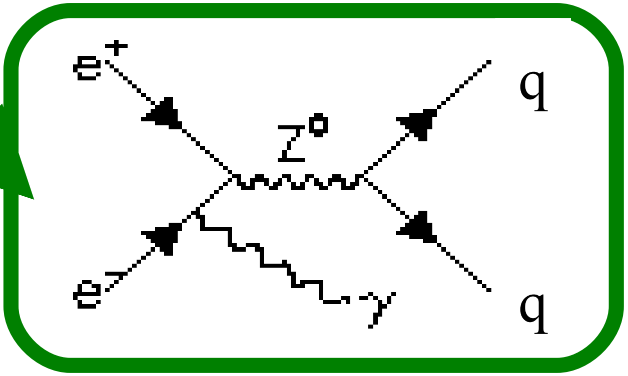
- 177 events are selected
  - 181 events expected from SM backgrounds
- The signal efficiencies
  - $H \rightarrow bb,cc,gg$: about 40%
- discriminant variable in C.L. calculation
  - the reconstructed Higgs boson mass

The tau lepton final state

- H→ττ, Z→qq
- cross section : 5.5% (Higgsstrahlung)
- 2 hadronic jets
- 2 oppositely charged, low multiplicity jets with missing E

Preselection

- select hadronic events
  - at least 8 charged tracks
  - E_{tot} from all charged particles > 20%√s
- suppress of WW and ZZ
  - $E_{lepton} < 25\%\sqrt{s}$
- reject radiative returns to the Z peak
  - $|\text{missing } p_z| + \text{missing } E < 1.8\gamma_{peak}$
  - $|\text{missing } p_z| < 60\%\gamma_{peak}$



selection criteria

- cluster into minijets
  - invariant mass < 2.7 GeV
  - select 2 τ candidates
- cluster into 2 jets
- kinematic consistency fit
  - χ^2 is calculated from
    - energy-momentum conservation
    - hadronic jet resolutions
    - the compatibility of the di-jet invariant masses
- select ττqq by 2 Neural Networks
- reduce the overlap with leptonic-final-state ($m_{\tau\tau} < 75$ GeV)

discrimination between ττqq, hττ and B.G.

- ττqq NN
  - 4 input variables (χ^2, p_T, sum of 2 τ minijet isolation angles, sum of fitted p_T of τ with respect to nearest hadronic jet)
  - training : ττqq, qq, WW, ZZ
- hττ NN
  - 5 input variables (ττqq NN inputs, sum of NN b-tag outputs)
  - training : hττ, qq, WW, ZZ
- higher NN output determines if ττqq or hττ

Result

- 27 events are selected
  - 27.2 events expected from SM backgrounds
- discriminant variable in C.L. calculation
  - the reconstructed Higgs boson mass

The four-jet final state

- $H \to qq$, $Z \to qq$
- cross section : 64.6% (Higgsstrahlung)
  - not including $H \to \tau\tau$
- main background
  - $ee \to qq(\gamma)$
  - $ee \to WW$
  - $ee \to ZZ$

Preselection 1

- at least 8 charged tracks
- E_{tot} of cahrged particles > 10%√s
- reject radiative returns to Z resonance
  - $p_z < 1.5(m_{vis} - 90)$
- cluster into 4 jets
- $y_{34} > 0.008$
- reject radiative returns to Z with γ in detector
  - less than 80% of E_{jet} is in the form of e and γ
- reject WW($W \rightarrow l\nu$)
  - $E_{e\ or\ \mu}$(most energetic) < 20GeV

Preselection 2

- avoid overlap with leptonic selection
  - $m^{ll} < 40$ GeV
- The signal efficiencies
  - h→bb,cc,gg : order of 70%
- Agreement between data and the expectation from SM

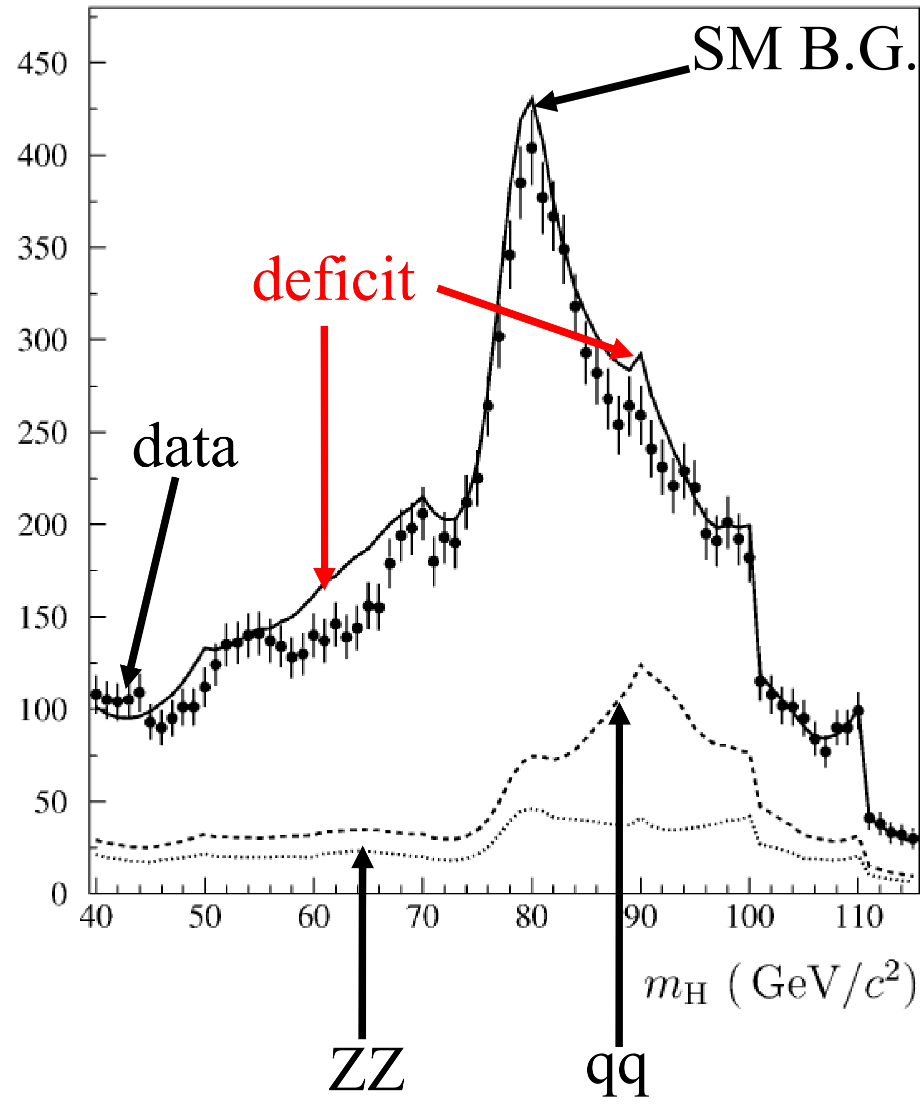
$\sqrt{s}$ (GeV)	Background process contributions				Data
	WW	$q\bar{q}$	ZZ	Total	
188.6	1002.1	261.5	63.8	1327.5	1242
191.6	165.2	41.9	11.8	218.9	221
195.5	459.8	108.1	35.7	603.4	614
199.5	492.3	108.0	40.0	640.1	624
201.6	238.9	51.2	19.7	309.7	261
204–209	1251.0	247.9	102.8	1601.6	1601
All $\sqrt{s}$	3609.3	818.6	273.8	4701.7	4563

Neural Network

- 6 variables (ε_{WW}, $S_{m_H}(\varepsilon_{HZ})$, $B_{m_H}(\varepsilon_{HZ})$, E_{jet}^{min}, E_{jet}^{max}, $E_{jet}^{min}\theta_{ij}$)
  - ε_{WW} : the significance of the distance to WW hypothesis
  - $S_{mH}(\varepsilon_{HZ})$, $B_{mH}(\varepsilon_{HZ})$: the probability density functions
  - ε_{HZ} : the significance of the distance to HZ hypothesis
- training : from m_H=40 GeV to 115 GeV in steps of 5 GeV
  : at E_{CM} = 189, 199.5, 206.7 GeV
- N_{95} prescription is used to determine the appropriate cut

Result

- a deficit is observed in the 60 GeV and 90 GeV regions
  - statistical fluctuation
- di-jet mass information is not included as a discriminant variables in C.L. calculation



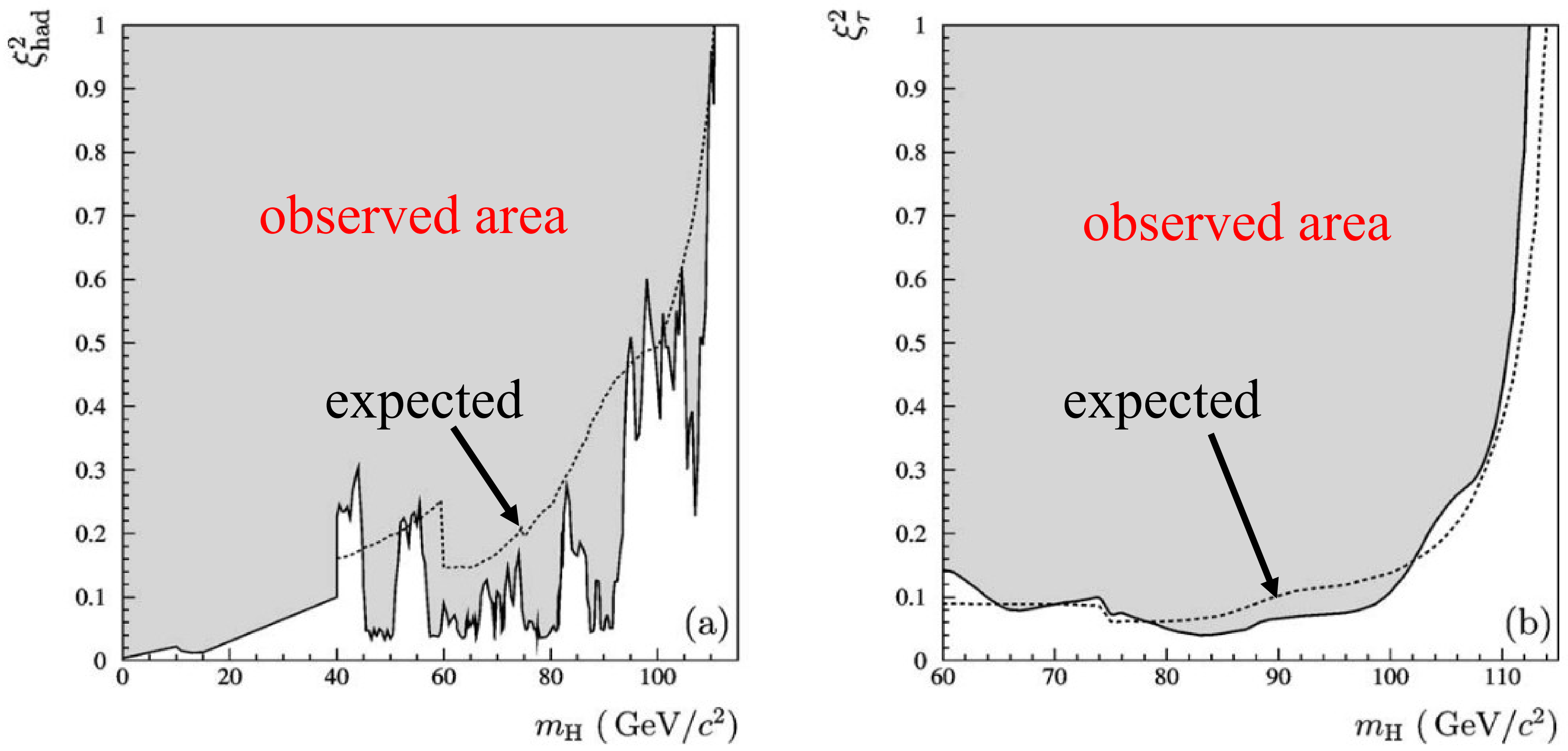
Results

- no departure from SM expectations consistent with the presence of a Higgs signal is observed

- Lower limits on the lightest scalar Higgs boson mass are derived as a function of ζ^2_{had} and ζ^2_{τ} (ζ^2 : branching fraction × ratio of production cross section to SM production cross section)
  - $\zeta^2_{had} = 1$
    - Higgs boson masses below 110.6 GeV are excluded at 95% C.L.
    - a limit of 110.5 GeV is expected in the absence of signal
  - $\zeta^2_{\tau} = 1$
    - Higgs boson mass below 112.4 GeV are excluded at 95% C.L.
    - a limit of 113.9 GeV is expected in the absence of signal
  - $\zeta^2_{had} + \zeta^2_{\tau} = 1$
    - a 109.1 GeV lower limit on m_H is obtained irrespective of ζ^2_{τ}

Results

- When parameters ζ^2_{had} and ζ^2_{τ} are allower to vary, the result is expressed as an excluded domain in the (m_H, ζ^2) plane



Conslusions

- Searches for higgs bosons produced via Higgsstrahlung decaying to hadrons and to tau leptons were performed in order to explore nonstandard Higgs scenarios.
- No evidence of Higgs boson production is observed in the search for either hadronic or tau decays in the data collected at energies between 189 and 209 GeV
- For a Standard Model Higgsstrahlung cross section and a 100% branching fraction to
  - hadrons
    - mass below 110.6 GeV are excluded at 95% C.L.
  - $\tau\tau$
    - mass below 112.4 GeV are excluded at 95% C.L.