

# Flavour independent neutral Higgs boson searches at LEP

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On behalf of the LEP collaborations



## LEP and the LEP data-set

- **The LEP collider:**

$e^+e^-$  collider at CERN operated 1989-2000  
(4 experiments: ALEPH, DELPHI, L3, OPAL)

$\sqrt{s} \approx m_Z$  (LEP1) and  $\sqrt{s} = 130-209$  GeV (LEP2)

Most results (95% CL limits) based on LEP2: Int. Lum.  $\approx 2.6 \text{ fb}^{-1}$

- **LEP combined results on Higgs searches:**

<http://lephiggs.web.cern.ch/LEPHIGGS/www/Welcome.html>

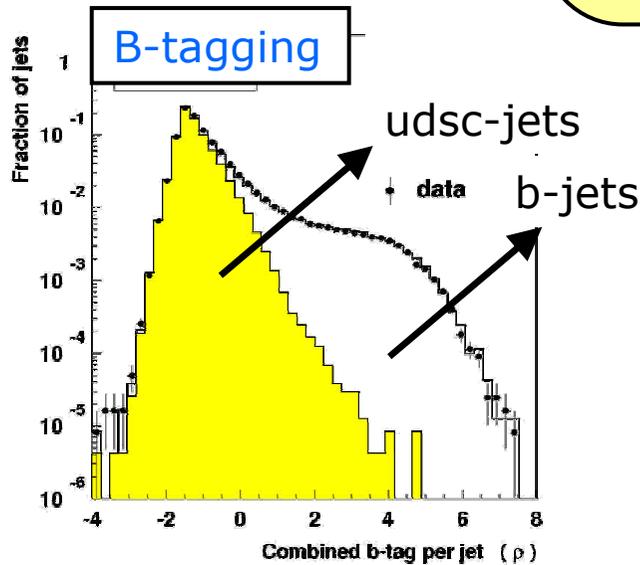
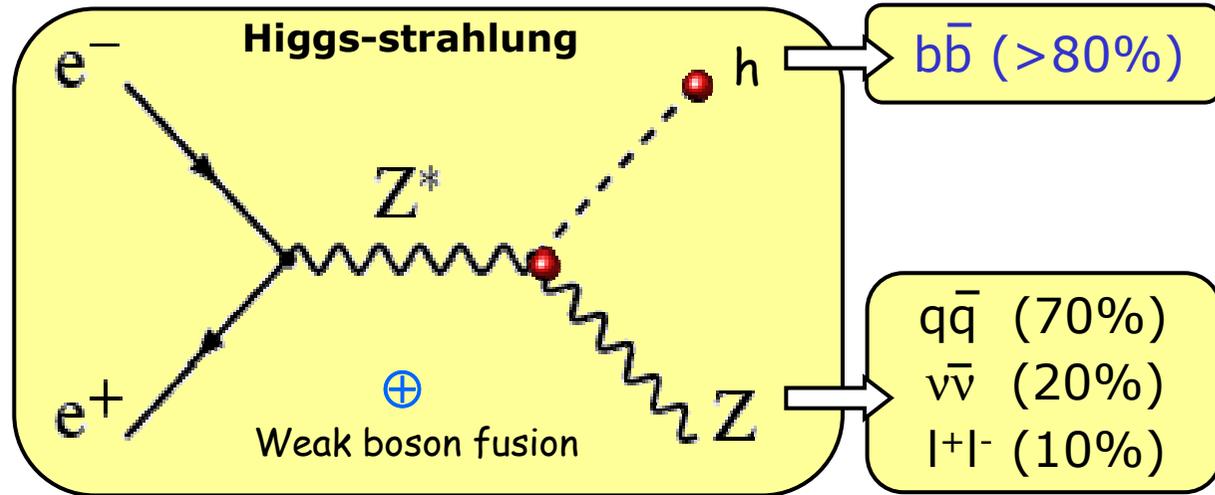


# SM Higgs boson

- In the SM we know everything about the Higgs boson (except its mass)

**Production:**  $\sigma_{hz}(m_h, \sqrt{s})$

**Decay:**  $\Gamma_h(m_h)$



- 2 b-jets + a "Z". Excluded SM  $m_h$ :

$m_h > 115.3$  GeV (expected)  
 $m_h > 114.4$  GeV (observed)



# Neutral Higgs boson production at LEP

- Simplest SM extension: 2 complex Higgs Doublets à 5 Higgs bosons (3 neutral)

Neutral Higgs boson production

Higgs strahlung

Associated production

$$\sigma_{hZ} = \sin^2(\beta - \alpha) \cdot \sigma_{hZ}^{SM}$$

$$\sigma_{hA} = \cos^2(\beta - \alpha) \cdot \lambda \cdot \sigma_{hZ}^{SM}$$

Higgs boson decay

Depends on model parameters

$$\frac{h \rightarrow b\bar{b}}{(h \rightarrow b\bar{b})_{SM}} \propto \frac{\sin^2(\alpha)}{\cos^2(\beta)}$$


Models: 2HDM(I): One doublet for all fermions  
 2HDM(II): One up-type doublet  
 One down-type doublet



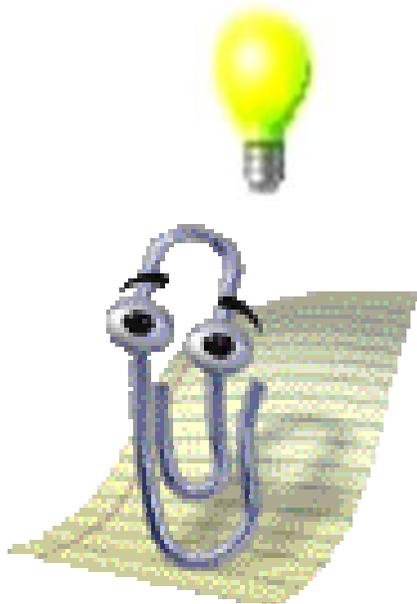
$h \rightarrow b\bar{b}$  decays suppressed (light quarks and gluons)

No sensitivity in standard analyses



## What if a neutral Higgs boson is produced, but

- ... does not couple (strongly) to b-quarks
- ... decays into light quarks or gluon pairs
- ... has a cross section  $\times$  times smaller or larger than SM prediction



### In general:

Test predictions of any (new) model against LEP data

### Experimentalist:

Exclude neutral Higgs boson production, with  $(H \rightarrow \text{hadrons})$  over  $m_H$  range

YES

NO

Cancel



## Neutral Higgs boson production at LEP

$$\begin{aligned}
 e^+e^- \rightarrow hZ &\implies \sigma_{Z(h\rightarrow f\bar{f})} = \boxed{\sigma_{hZ}^{\text{EW}}} \times \boxed{C_{Z(h\rightarrow f\bar{f})}^2} \\
 e^+e^- \rightarrow hA &\implies \sigma_{hA\rightarrow f\bar{f}f\bar{f}} = \boxed{\sigma_{hA}^{\text{EW}}} \times \boxed{C_{hA\rightarrow f\bar{f}f\bar{f}}^2}
 \end{aligned}$$

$\downarrow$   $SU(2) \times U(1)$        $\downarrow$  Details Higgs sector

Assumption:  $\Gamma_h$  small (w.r.t detector resolution)

- **Flavour independent (hadronic) Higgs boson search:**

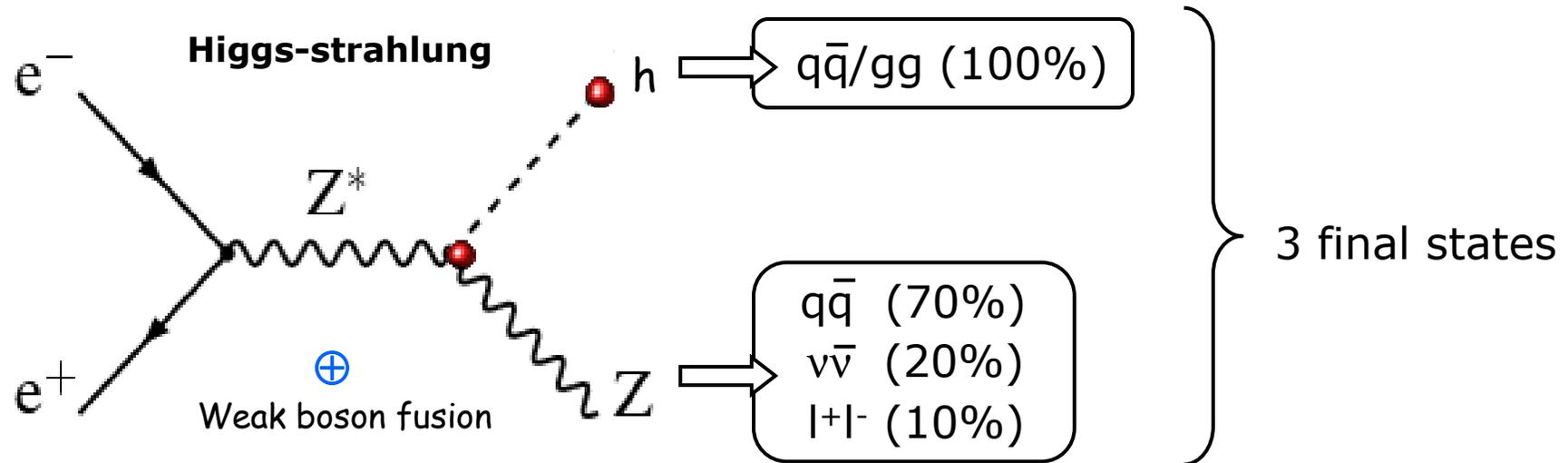
Topology based (no b-tag information)

Consider Higgs boson decays into all quark pairs and gluons

↳ Worst case scenario  $\rightarrow$  Exclude  $C_{hZ}^2(m_h)$  and  $C_{hA}^2(m_h, m_A)$



## hZ production



**SM Backgrounds:**  
 $q\bar{q}(\gamma), W^+W^-, ZZ$

### Experimental issues:

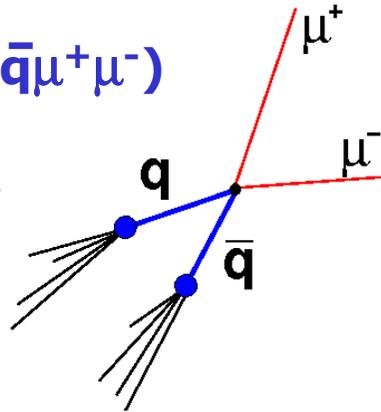
- à  $q\bar{q}\nu\bar{\nu}/q\bar{q}l+l^-$ : Z-like object + recoil mass
- à 4-jets: topology+ masses (3 pairings)
- à Gluon pairs versus light-quark pairs:  
 higher selection efficiency  $\leftrightarrow$  worse di-jet mass resolution

# hZ production: single experiment



## Single channel ( $q\bar{q}\mu^+\mu^-$ )

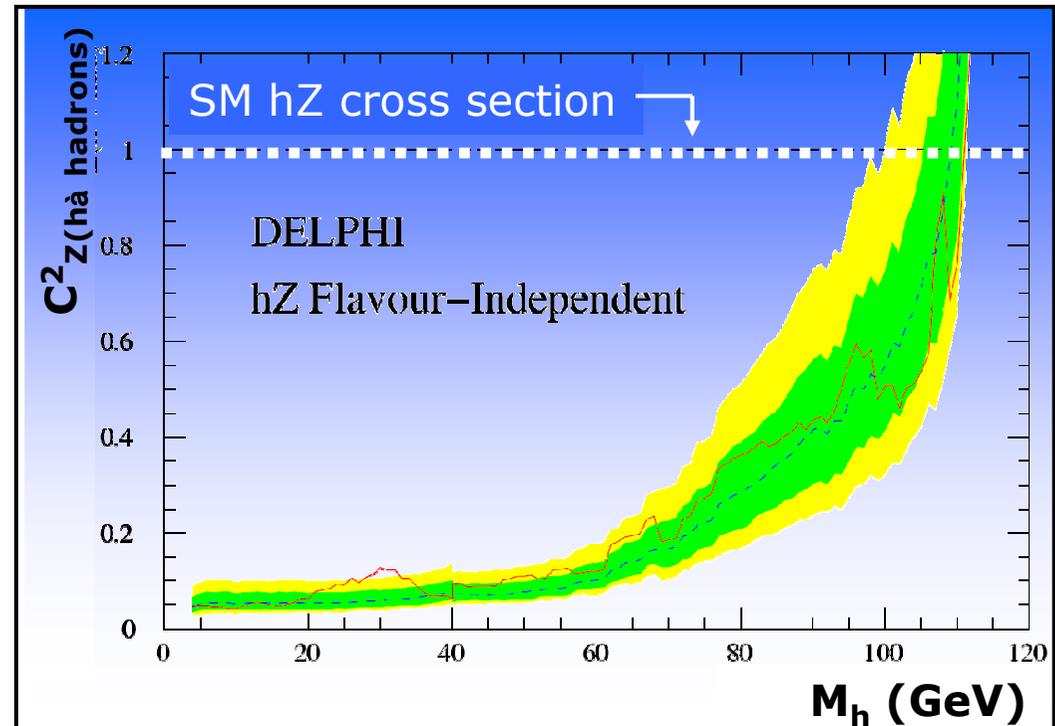
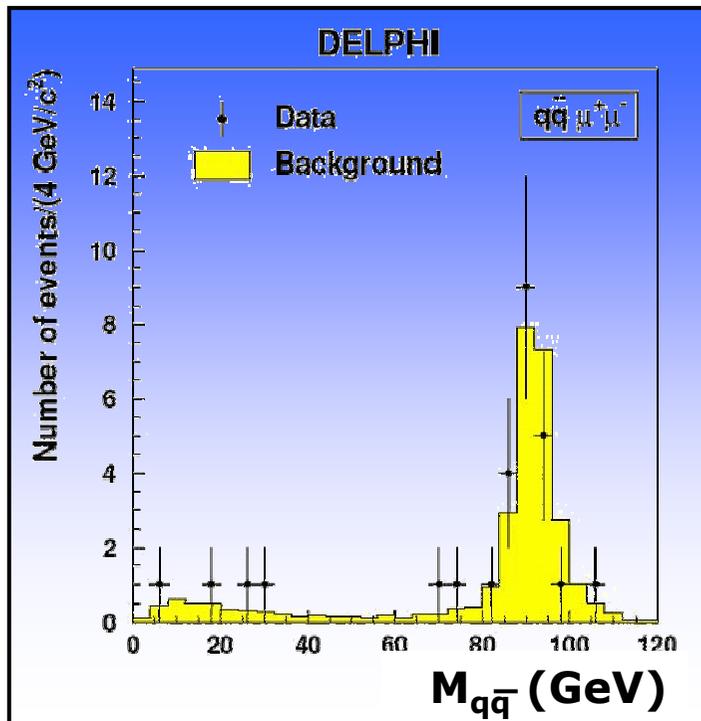
only 3% of all decays, but very clean



## DELPHI (all channels)

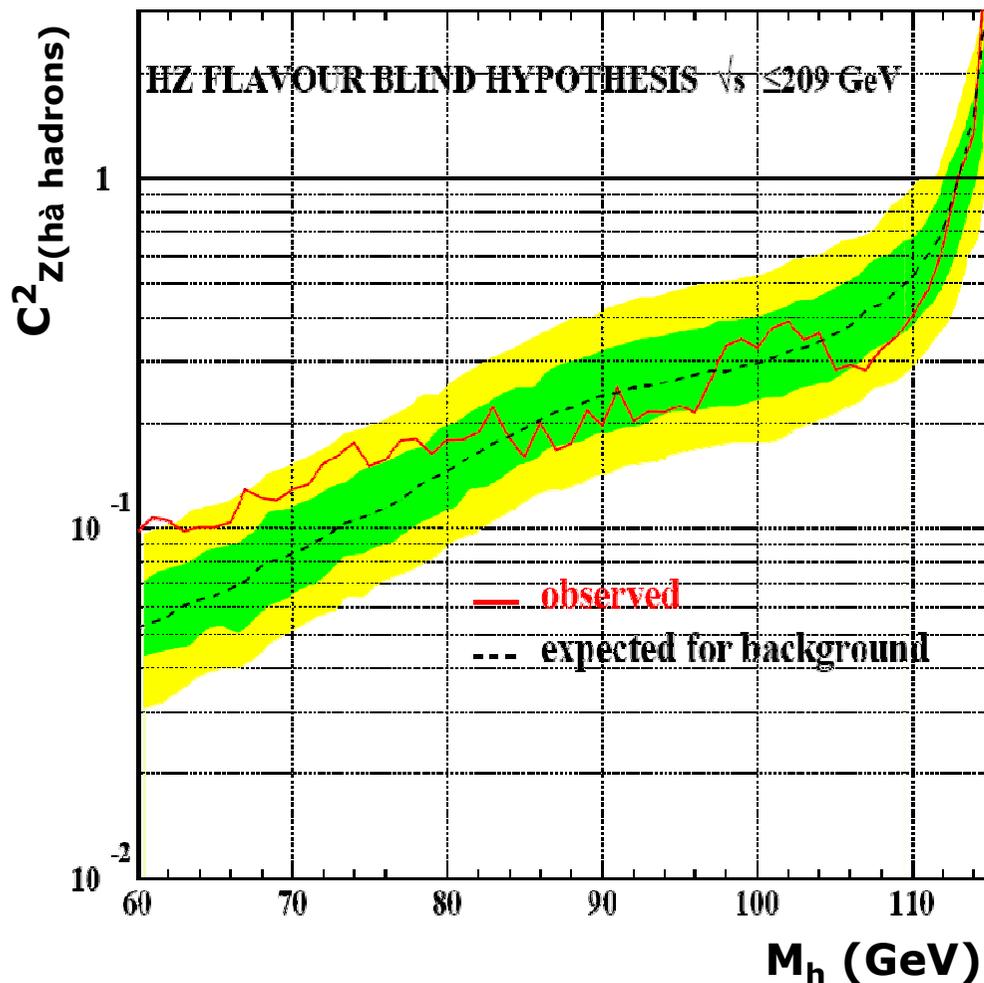
Topologies:  $q\bar{q}q\bar{q}$ ,  $q\bar{q}v\bar{v}$ ,  $q\bar{q}l+l-$

Mh range:  $4 < M_h < 115$  GeV





## LEP PRELIMINARY



### LEP results on hZ production:

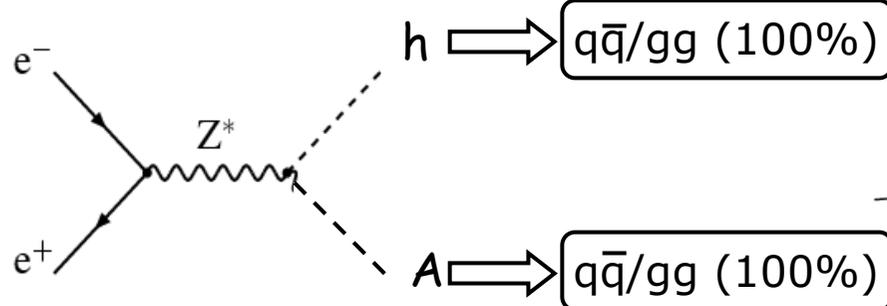
	Expected (GeV/c <sup>2</sup> )	Observed (GeV/c <sup>2</sup> )
Flav.Ind.	113.0	112.9
SM	115.3	114.4

Even without b-tag information, still a strong limit

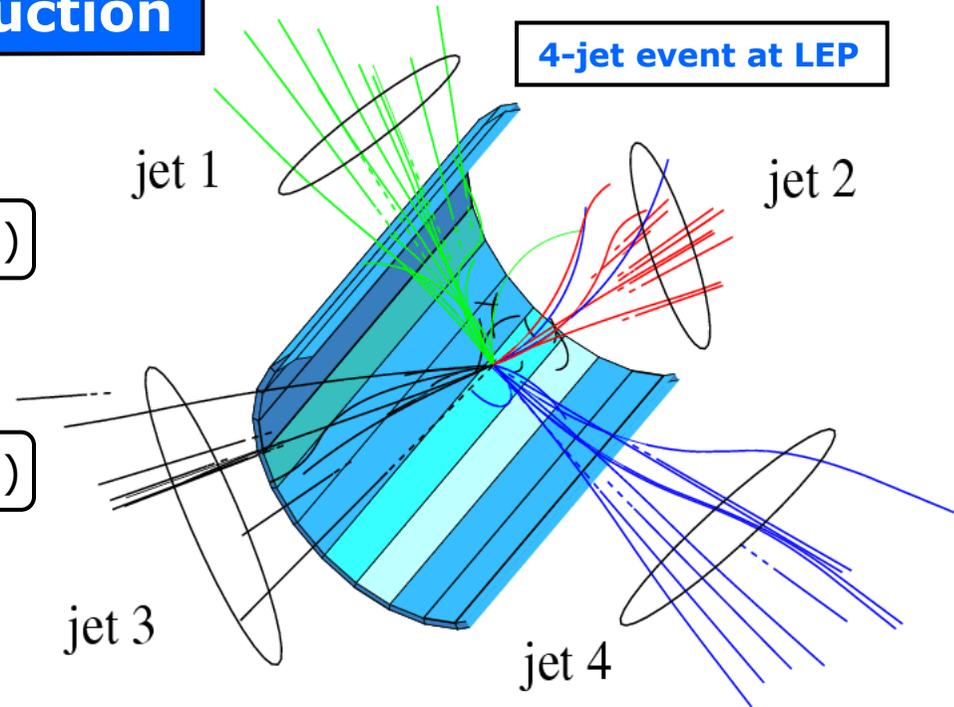


# hA production

## Associated production



4-jet final state



## Experimental issues:

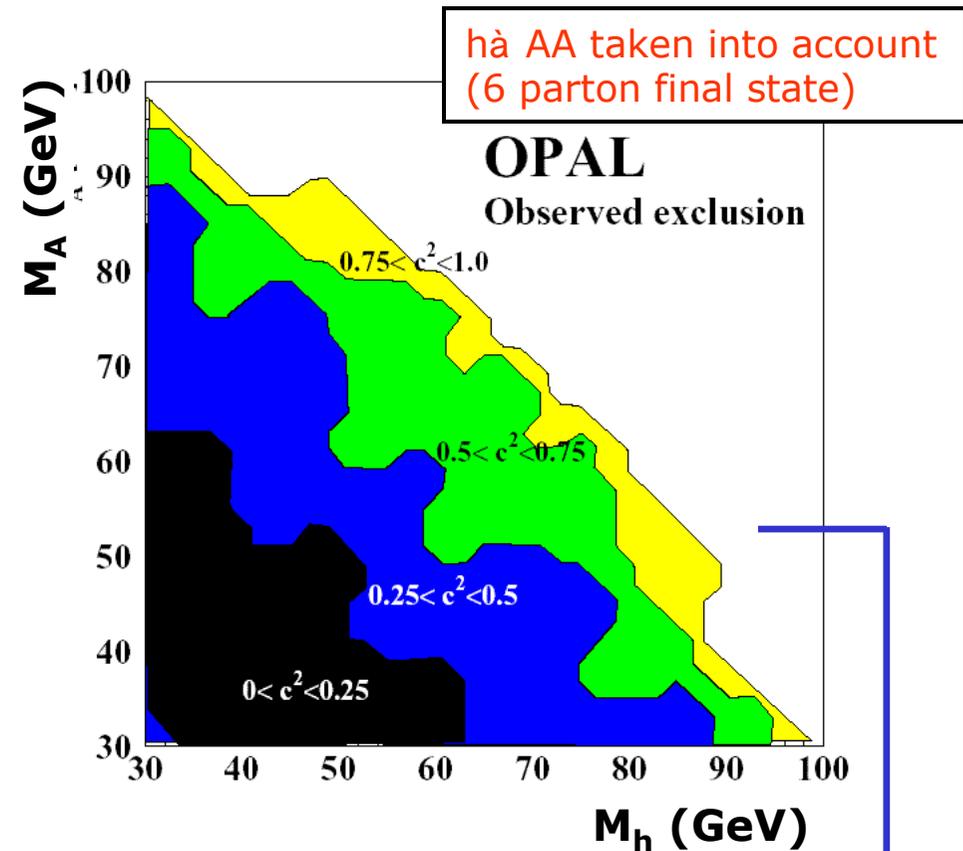
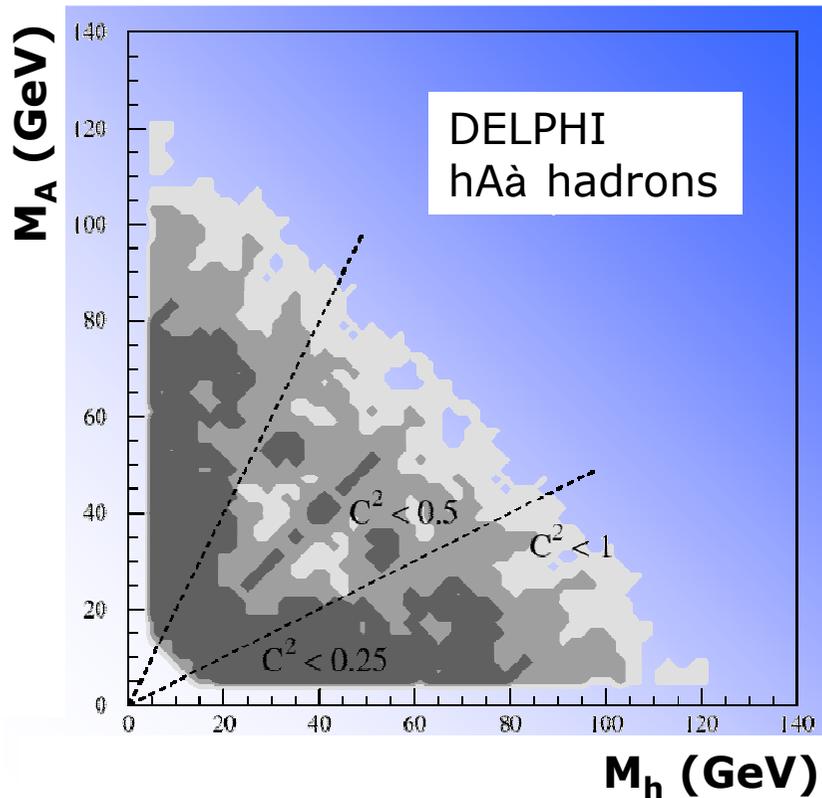
- à Analyses depend on h and A masses  
Topology (small  $m_h$  or  $m_A$ : 4 jets à 3 jets)  
OPAL: also consider  $h \rightarrow AA$
- à Pairing ambiguities: 4 jets (3 pairings)
- à Gluon pairs versus light-quark pairs:  
higher selection efficiency  $\leftrightarrow$  worse di-jet mass resolution

### SM Backgrounds:

$q\bar{q}(\gamma)$	$\sim 8$	pb
$W^+W^-$	$\sim 8$	pb
$ZZ$	$\sim 0.5$	pb



- Exclude hA(hadronic) cross-sections relative to SM:  $C_{hA}^2(m_h, m_A)$



For  $C^2 = 1$ :  $m_h + m_A < 140$  GeV

- Interpretation in 2HDM models (parameter scan): see talk by P. Akesson



## Conclusions

- **Limits on  $hZ$  and  $hA$  production ( $h, A \rightarrow$  gluons/quarks)**

LEP combined results on  $hZ$  (No signal observed)

Cross section exclusion as function of  $m_h$  ( $m_A$ )

- **Important experimental LEP legacy:**

More **model independent** summary of LEP data

Important test for (future) model builders

... SUSY, 2-3-4-5HDM, CP (non-)conserving, etc.

LHC cannot easily cover low mass regions  
(allows check for any LHC prediction)