Search for Charged Higgs Bosons with the OPAL Detector at LEP

Dezső Horváth

Research Institute for Particle and Nuclear Physics, Budapest and Institute of Nuclear Research, Debrecen, Hungary

Outline

- The Standard Modell and its extensions
- LEP experiments (†† RIP)
- Charged Higgs bosons
- Event selection
- Mass limits
- Conclusion

The Standard Model

Fermions	isospin doublets (families)	charge
Leptons	$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L$	$\begin{matrix} 0 \\ -1 \end{matrix}$
Quarks	$\begin{pmatrix} u \\ d' \end{pmatrix}_L \begin{pmatrix} c \\ s' \end{pmatrix}_L \begin{pmatrix} t \\ b' \end{pmatrix}_L$	$\begin{matrix} +2/3 \\ -1/3 \end{matrix}$

Composite particles: Two quark combinations

hadrons = mesons ($q\overline{q}$) + baryons (qqq)

Interactions from local gauge invariance

Free Dirac fermion (weak isodoublet) **+**

$$U(1) \quad \otimes \quad SU(2) \quad \otimes \quad SU(3)$$

$\Downarrow$ electroweak $\qquad$ $\Downarrow$ strong

+ Higgs field $\Updownarrow$ (weak isodoublet)

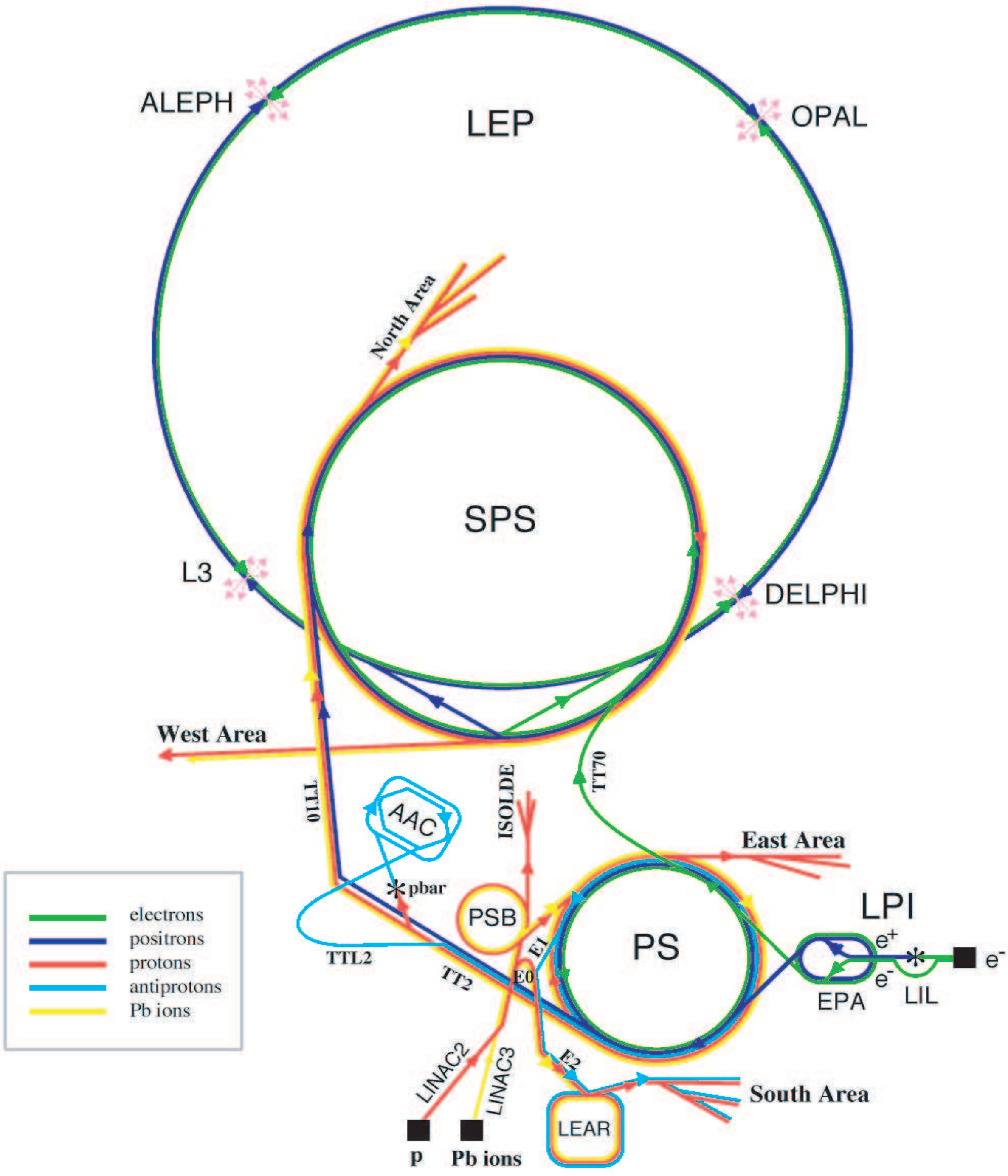
spont. symmetry breaking $\Updownarrow$ (vacuum exp. value $v \neq 0$)

$\longrightarrow$ renormalisation, consistency, masses

Experiment: SM works well, all predictions OK

Theory: many problems

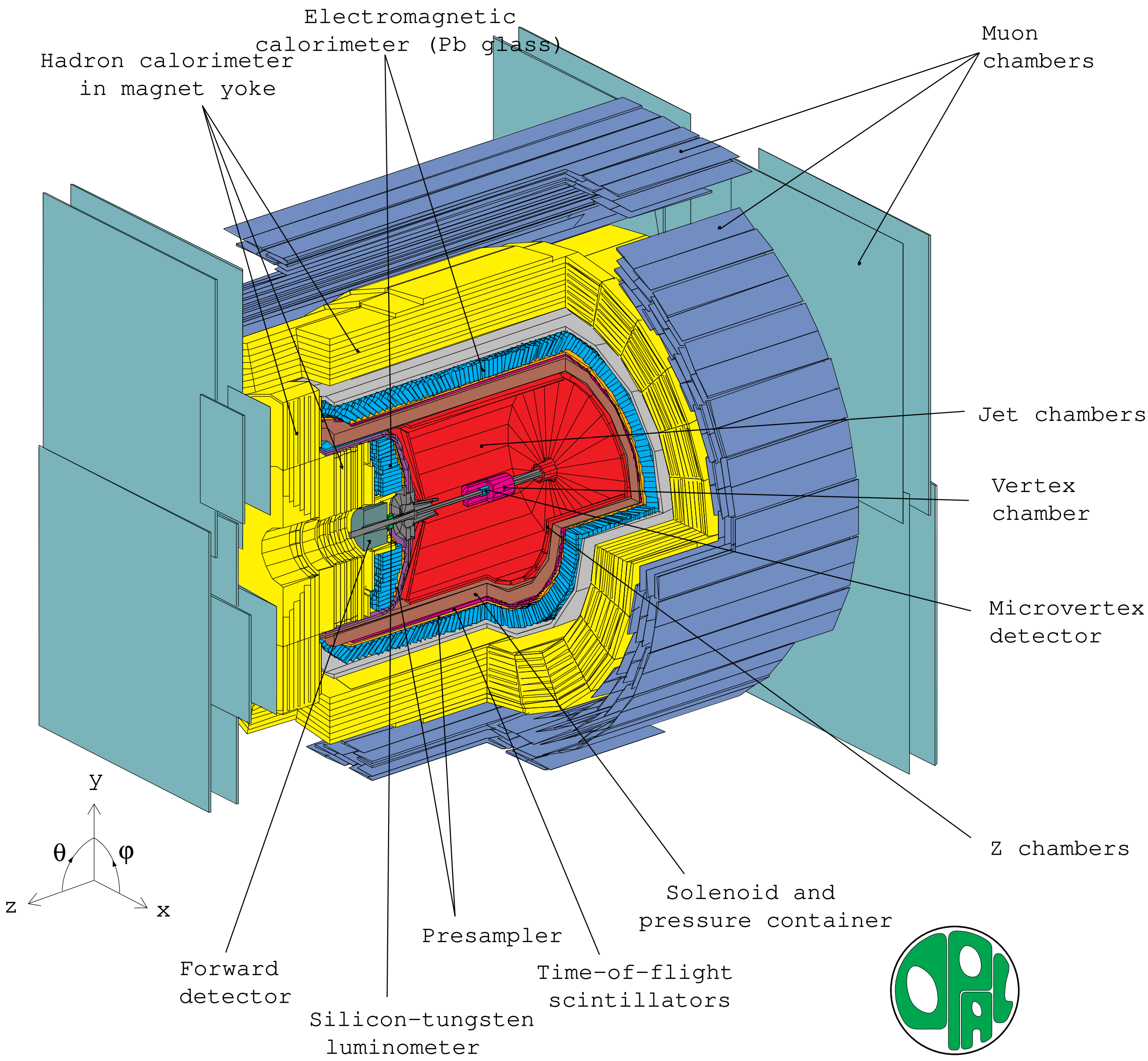
LEP at CERN



Accelerators at CERN 1989–2000

The OPAL detector at LEP

Omni-Purpose Apparatus for LEP



Smallest LEP detector: ∅10 m × 10 m

Smallest LEP collaboration: 300 participants

Higgs bosons

The Standard Model Higgs mechanism

$+$ complex doublet $\phi \rightarrow$ $+$ 4 degrees of freedom
3 masses $(W^{\pm}, Z) + H$
V_{min} at $\phi = \begin{pmatrix} 0 \\ v \end{pmatrix}$

$v \sim 246$ GeV vacuum exp. value

Spinless neutral heavy particle, not found yet

LEP:	114 GeV	$< M_H <$	180 GeV	
	direct search		SM fitting	

Two Higgs Doublet Models (2HDM)

2 Higgs doublets $\rightarrow$ $+$ 8 degrees of freedom

3 masses $W^{\pm}$, Z $+$ 5 Higgs bosons h^0, A^0, H^0, $H^{\pm}$

h^0 is similar to SM H; decisive difference: $H^{\pm}$

Look for $e^+e^- \rightarrow H^+H^-$

Search for charged Higgs bosons

Assume pair production

$$\mathrm{e^+e^-} \to \mathrm{H^+H^-}$$

Decay to heavy fermions

$$\mathrm{H}^+ \to \begin{cases} \tau^+\nu_\tau \\ \mathrm{q\bar{q}'}(\sim \mathrm{c\bar{s}}) \end{cases}$$

Three channels ⇒ three analyses:

$$\mathrm{e^+e^-} \to \mathrm{H^+H^-} \to \begin{cases} \tau^+\nu_\tau\tau^-\bar{\nu}_\tau \\ \text{(leptonic)} \\ \tau^+\nu_\tau\bar{\mathrm{c}}\mathrm{s} + \tau^-\bar{\nu}_\tau\mathrm{c\bar{s}} \\ \text{(semi} - \text{leptonic)} \\ \mathrm{c\bar{s}\bar{c}s} \\ \text{(hadronic)} \end{cases}$$

($\mathrm{e^+e^-} \to \mathrm{H^+H^-} \to \mathrm{AW^*}$ in preparation)

$e^+e^- \to H^+H^-$: data sets

OPAL preliminary

Leptonic channel (1998–2000)

$E_{\rm cm}$ (GeV)	$< E_{\rm cm} >$	$E_{\rm cm}^{\rm MC}$	$\int \mathcal{L} dt$ (pb^{-1})
186–190	188.6	189	183.5
190–194	191.6	192	29.3
194–198	195.5	196	76.4
198–201	199.5	200	76.6
201–204	201.9	202	45.5
204–206	205.1	205	79.0
206–207	206.5	206	124.6
207–209	207.9	208	9.0

Semi–leptonic and hadronic channels (1998–2000)

$E_{\rm cm}$ (GeV)	$< E_{\rm cm} >$	$E_{\rm cm}^{\rm MC}$	$\int \mathcal{L} dt$ (pb^{-1})
186–190	188.6	189	179.6
190–194	191.6	192	29.3
194–198	195.5	196	76.3
198–201	199.5	200	75.9
201–203	201.9	202	36.6
203–209	206.0	206	217.4

CM–energy ranges, luminosity–weighted averages, energies used for Monte Carlo simulations, and integrated luminosities of the data.

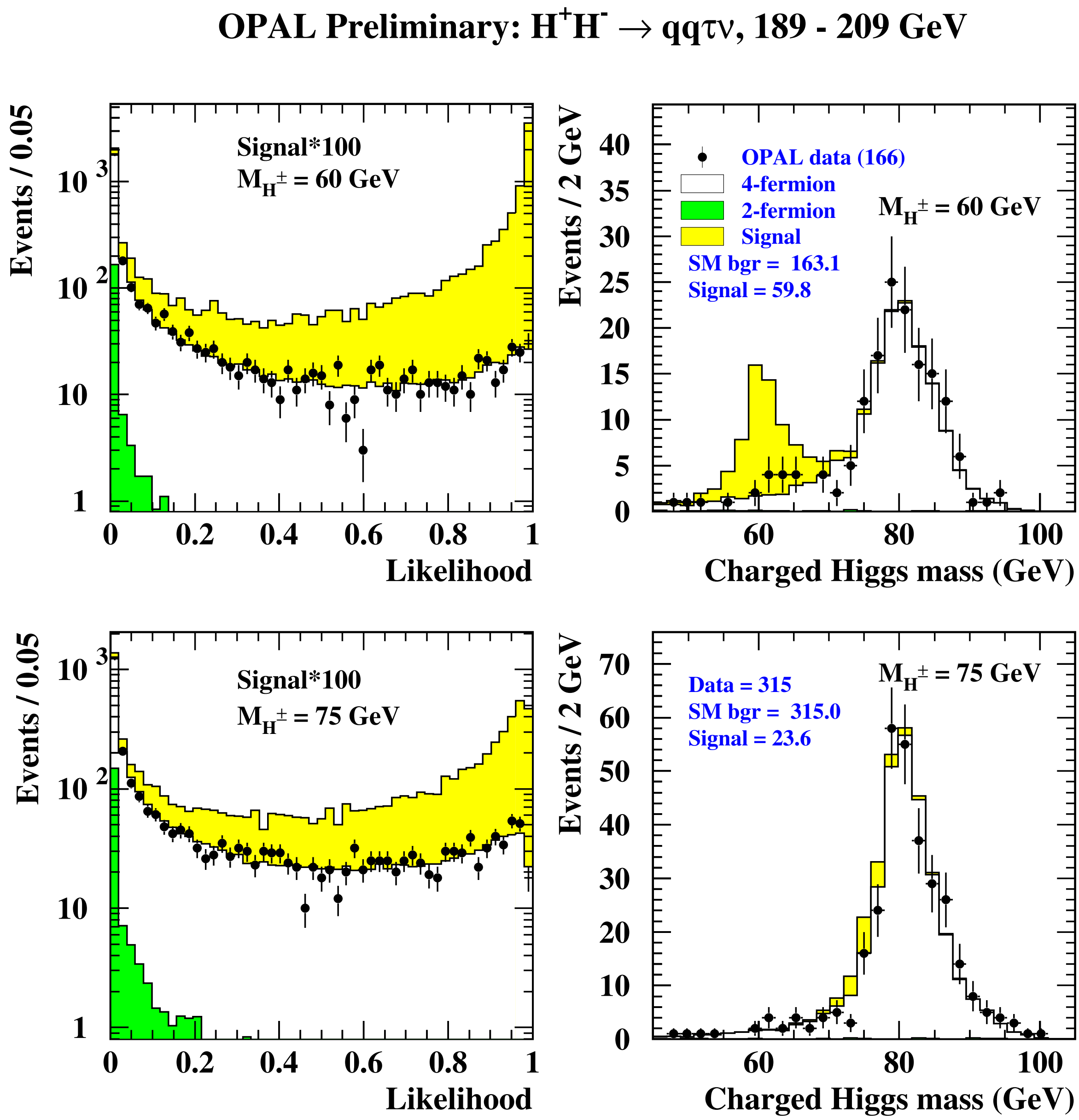
OPAL preliminary

Leptonic channel, E_{CM} = 189–209 (GeV)

$m_{H^\pm}$ (GeV)	Data	SM background	Efficiency (%)
50.	1072.	1049.1 $\pm$ 3.0	71.1 $\pm$ 0.3
55.	1099.	1077.1 $\pm$ 3.0	73.4 $\pm$ 0.3
60.	1066.	1056.3 $\pm$ 3.0	75.2 $\pm$ 0.3
65.	1122.	1098.5 $\pm$ 3.0	76.5 $\pm$ 0.3
70.	1132.	1107.9 $\pm$ 3.0	78.2 $\pm$ 0.3
75.	1136.	1107.0 $\pm$ 3.0	78.7 $\pm$ 0.3
80.	1106.	1085.0 $\pm$ 3.0	79.2 $\pm$ 0.3
85.	1124.	1106.3 $\pm$ 3.0	80.1 $\pm$ 0.3
90.	1087.	1065.6 $\pm$ 3.0	80.7 $\pm$ 0.3
95.	780.	746.5 $\pm$ 2.3	79.8 $\pm$ 0.3
100.	456.	440.0 $\pm$ 1.8	47.6 $\pm$ 0.3

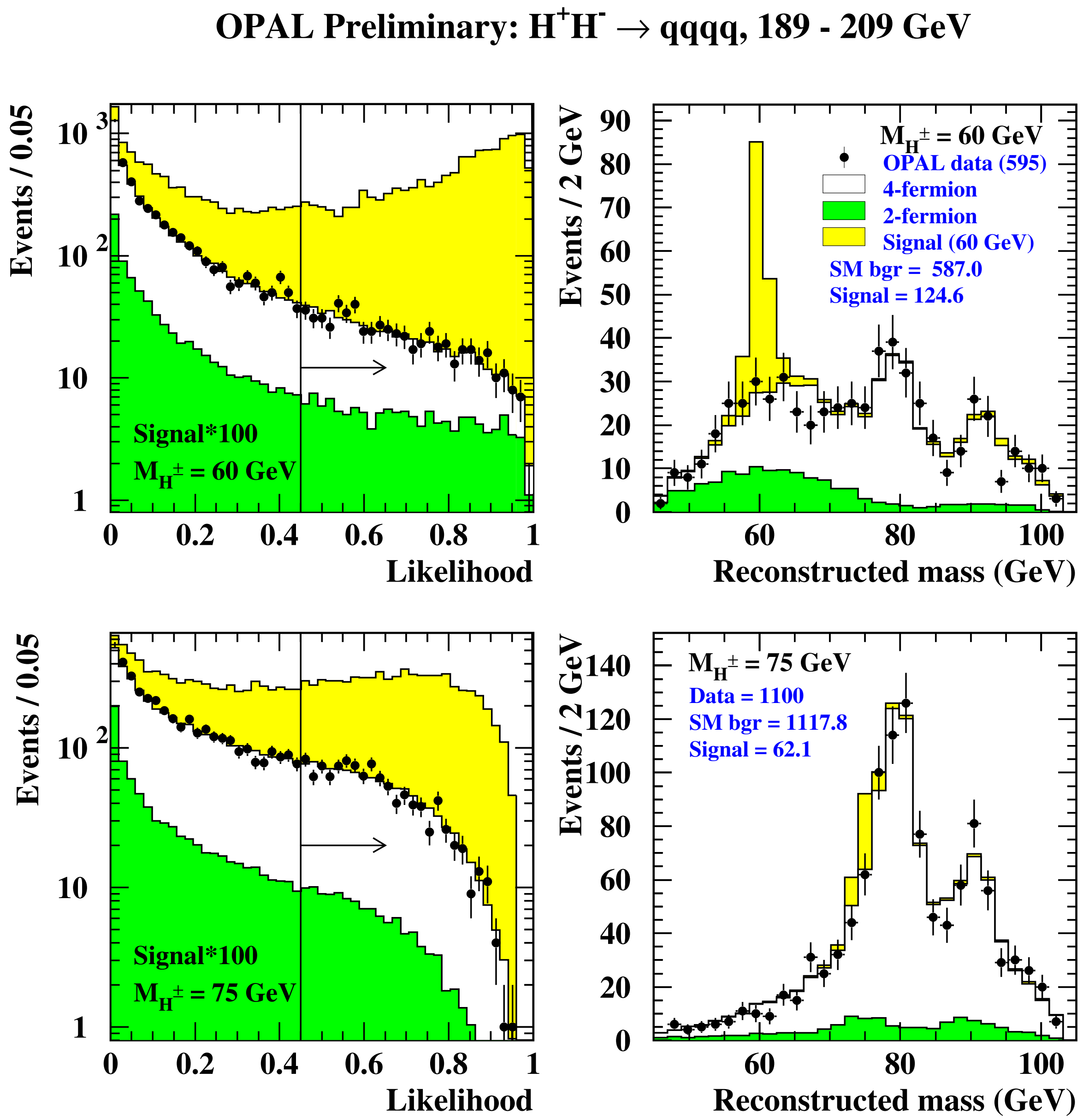
Selected and expected events for different values of $m_{H^\pm}$ with selection efficiencies averaged using luminosity weights for all analysed centre–of–mass energies.

$e^+e^- \to H^+H^- \to qq\tau\nu$



Likelihood distribution and mass spectrum after likelihood cut for two different charged Higgs boson masses for the semi–leptonic channel

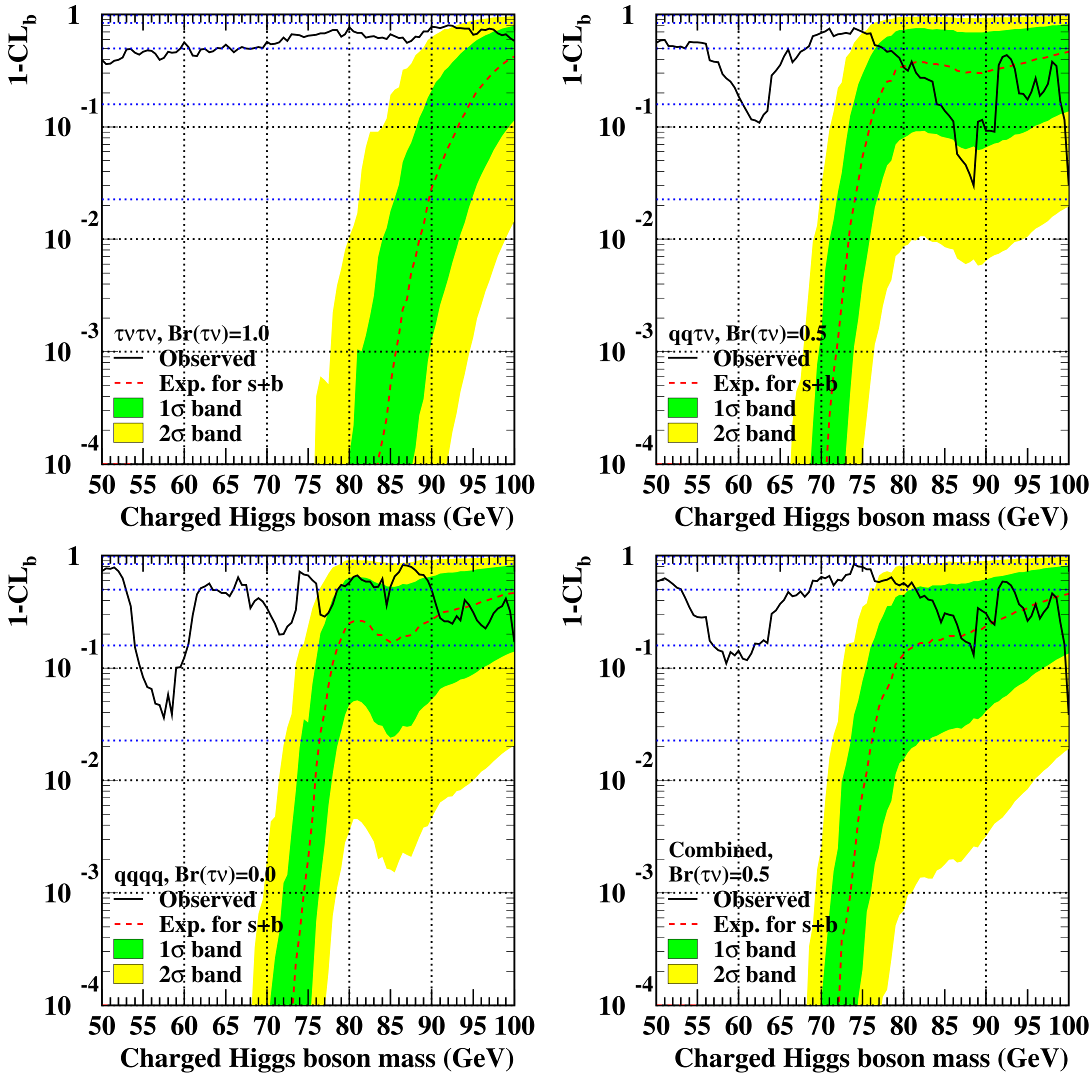
$e^+e^- \to H^+H^- \to qqqq$



Likelihood distribution and mass spectrum after likelihood cut for two different charged Higgs boson masses for the hadronic channel

$e^+e^- \to H^+H^-$: background only

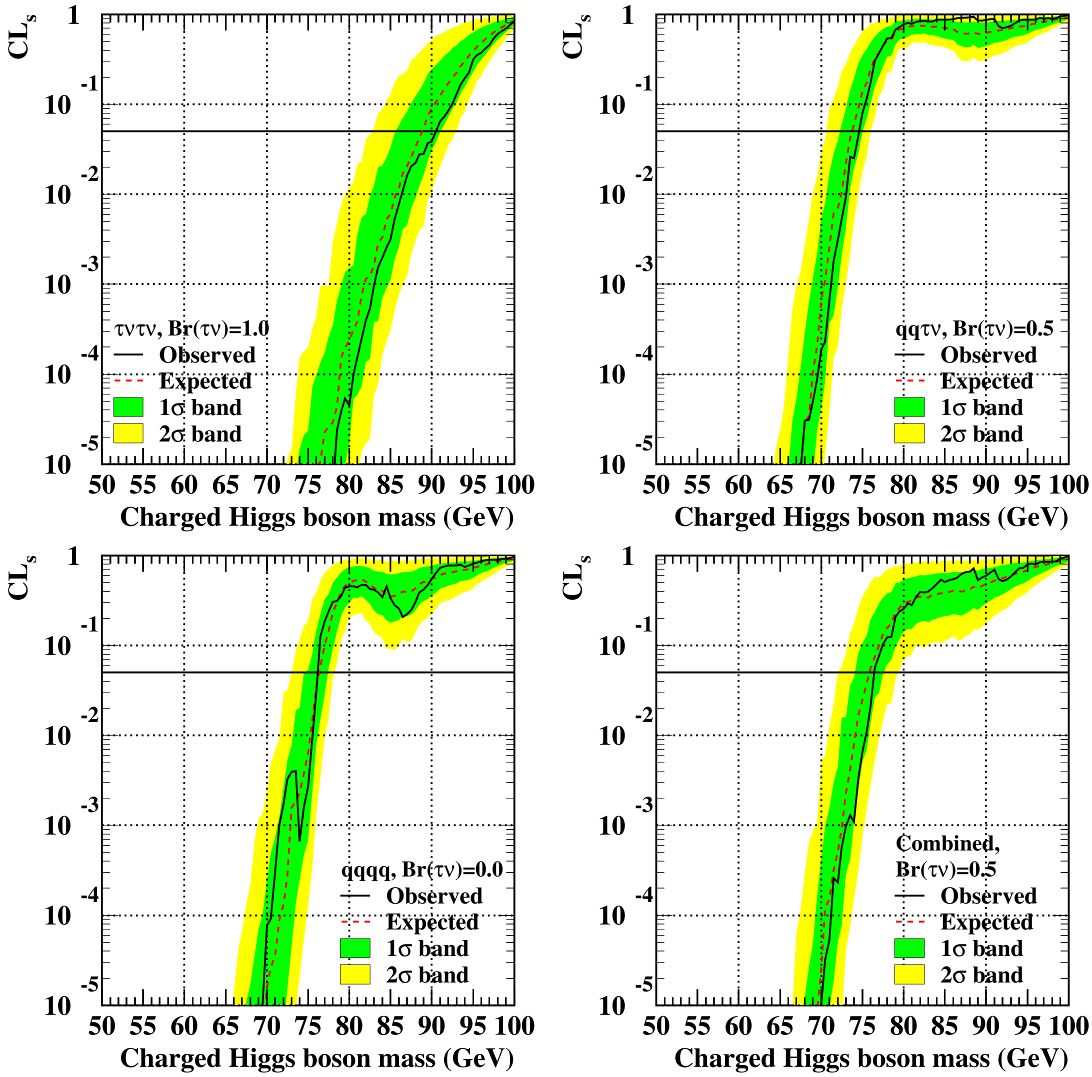
OPAL Preliminary



Confidence level for background interpretation of data together with expectation for signal+background experiments interpreted in terms of background

$e^+e^- \to H^+H^-$: signal + background

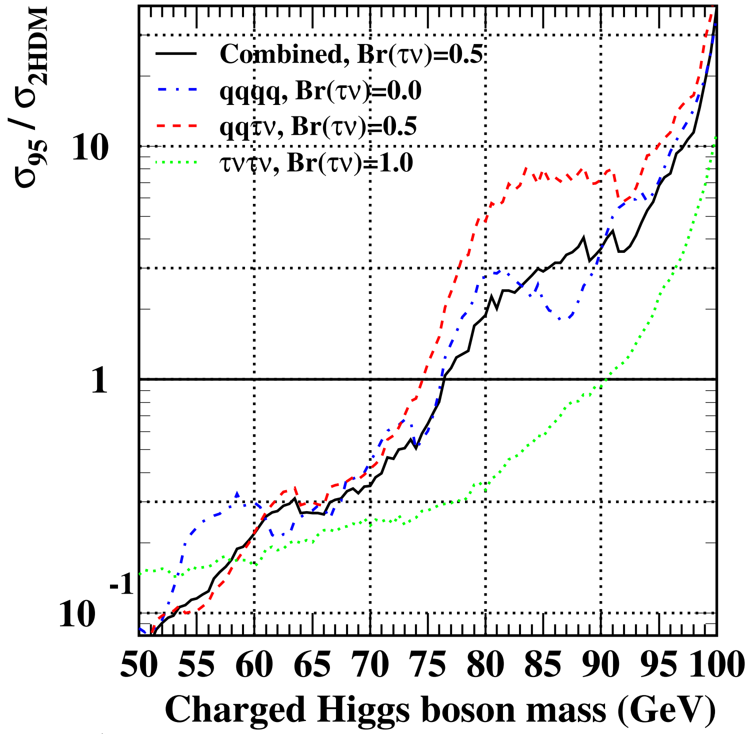
OPAL Preliminary



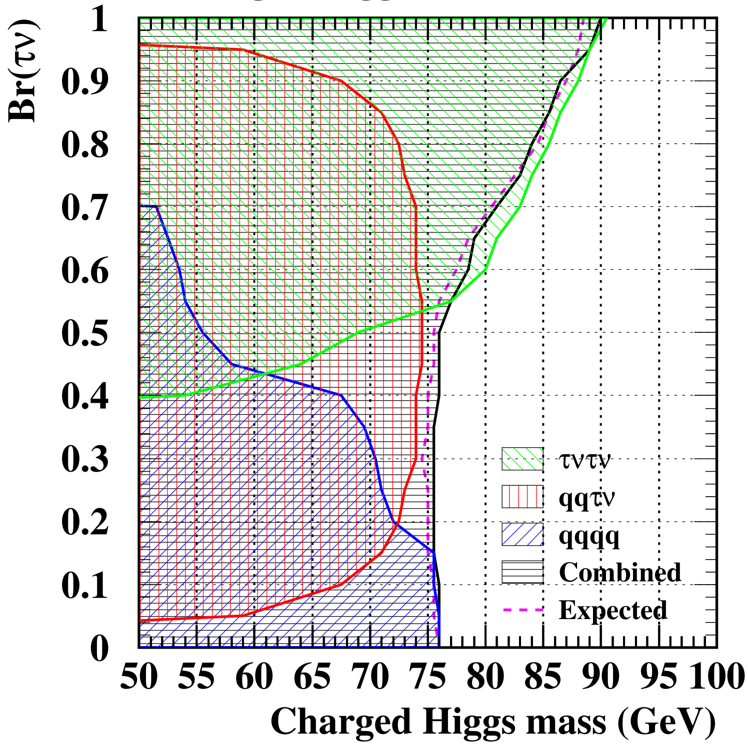
Observed and expected signal confidence levels $CL_S = CL_{S+B}/CL_B$ for the leptonic, semi–leptonic and hadronic channels and all three combined at $\mathrm{BR}(\mathrm{H}^\pm \to \tau\nu_\tau) = 0.5$

$e^+e^- \to H^+H^-$: limits

OPAL Preliminary



Cross section upper limit (at 95% CL) divided by the cross section predicted by 2HDM.



Regions of the mass – branching ratio plane excluded (at 95% CL) by the search channels. Expected limit is also shown for the combined case

$m_{H^\pm} < 75.5$ GeV (95% C.L.)

Comparison with other expts

Method	$E_{\rm cm}$ (GeV)	$m_{\rm H^\pm}$	collab.
$\rm e^+e^- \to H^+H^-$ $\rm H^\pm \to cs, \tau\nu$	189–209	> 79.3	ALEPH
	183–208	> 75.0	DELPHI†
	183–202	> 67.4	L3
	183–209	> 75.5	OPAL†
$\rm t \to H^+ b$	1800	> 158	CDF*
$\rm H^+ \to \tau^+ \nu_\tau$	1800	> 150	D0*

†Preliminary result

*For large $\tan\beta = \frac{v_1}{v_2}$

Summary

SM works well but no Higgs seen

(neither neutral nor charged)

OPAL: $m_{\mathrm{H}^\pm} > 75.5$ GeV (95% CL)

independent of branching ratio $\mathrm{BR}(\mathrm{H}^\pm \to \tau\nu_\tau)$,

assuming $\mathrm{BR}(\mathrm{H}^\pm \to \mathrm{q\bar{q}}) + \mathrm{BR}(\mathrm{H}^\pm \to \tau\nu_\tau) = 1$.

Outlook

- OPAL data: to include $\mathrm{e^+e^- \to H^+H^- \to AW^*}$
- final results in 2003
- LEP combination limit in 2003
- TEVATRON works $(\mathrm{H}^\pm \to \tau\nu)$
- LHC starts in 2007 $(\mathrm{H}^\pm \to \tau\nu$, tb)
- Observation will confirm, non–existence exclude 2HDM extensions.