Have we missed a Higgs at LEP?

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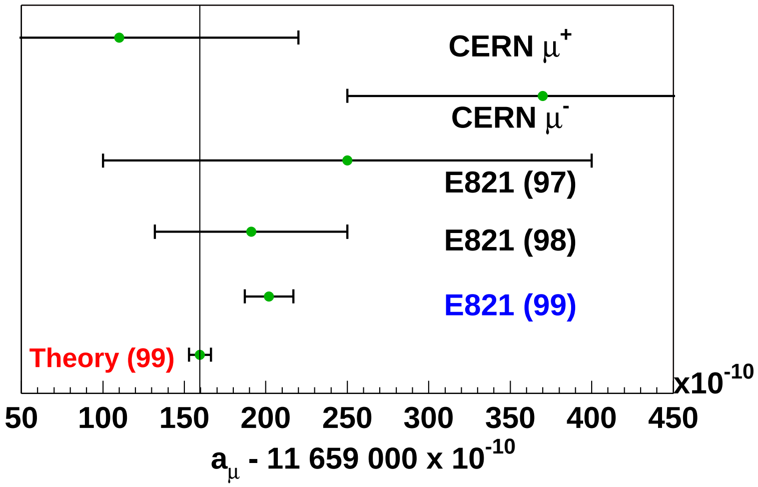
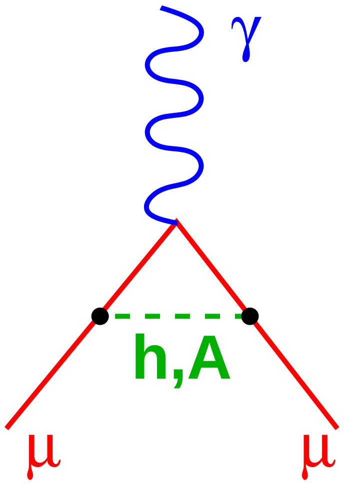
(Flavour independent searches and anomalous production and decay of Higgs bosons at LEP)

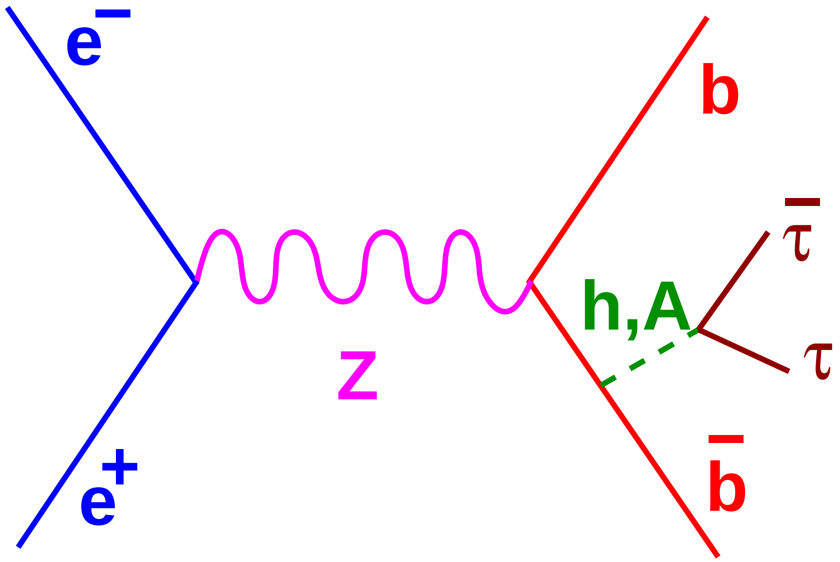
- Introduction. Dedicated searches
- Relaxing the assumptions
  - "All h,A" possibilities
  - "Flavour-independent" searches
  - "Model-independent" deviations
  - "Decay-independent" searches
- Summary

Triggered by





Higgs signature



$4\ \text{GeV} < m_h, m_A < 12\ \text{GeV}$

Large couplings to down-type quarks

h,A$\rightarrow b\bar{b}$ kinematically forbidden

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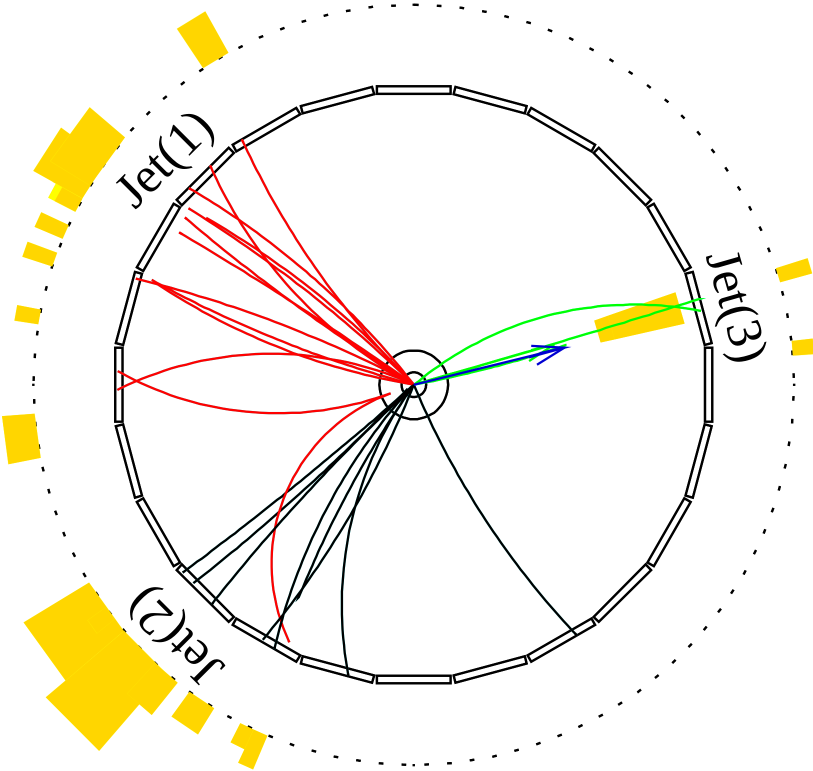
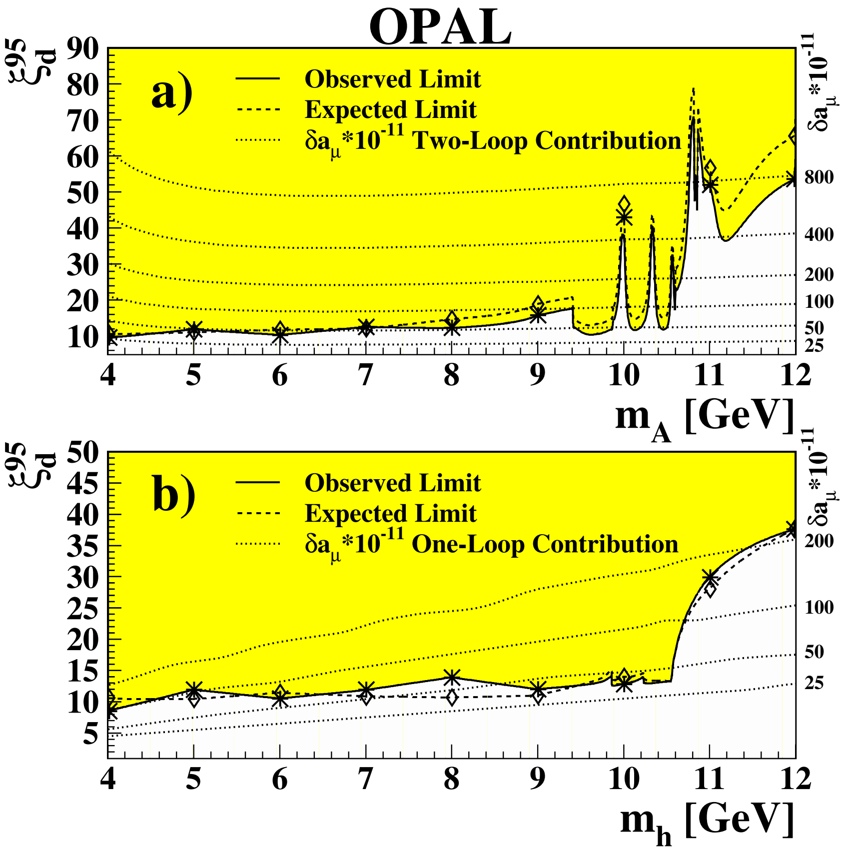
OPAL: Nothing found

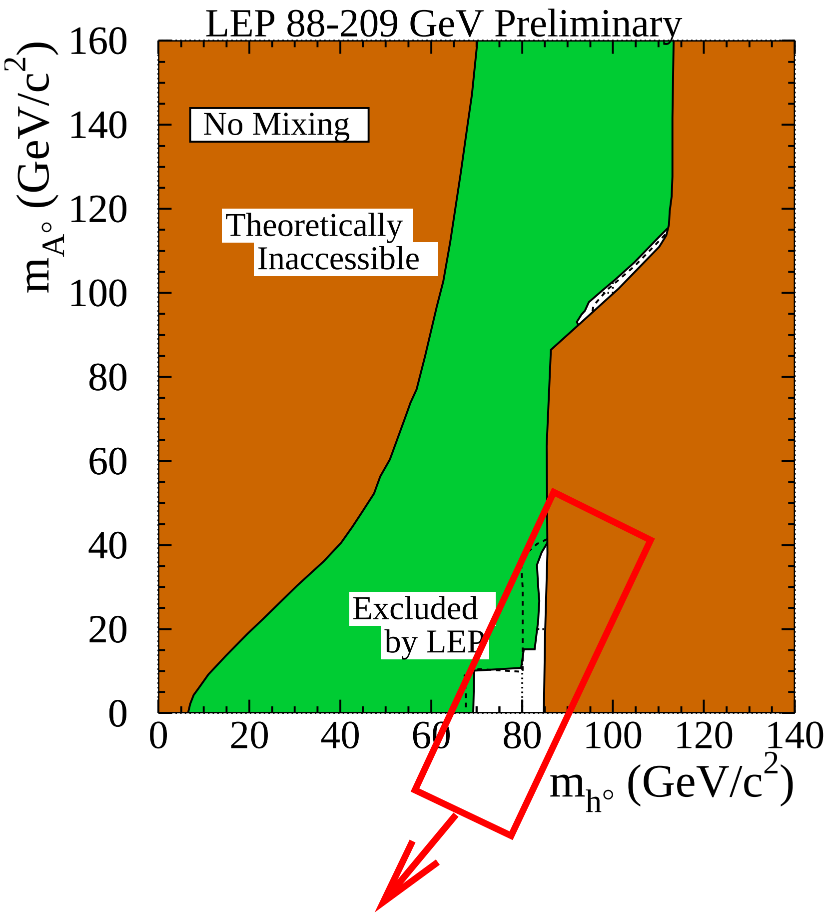




Disfavours a low mass Higgs explanation to any large δa_μ discrepancy

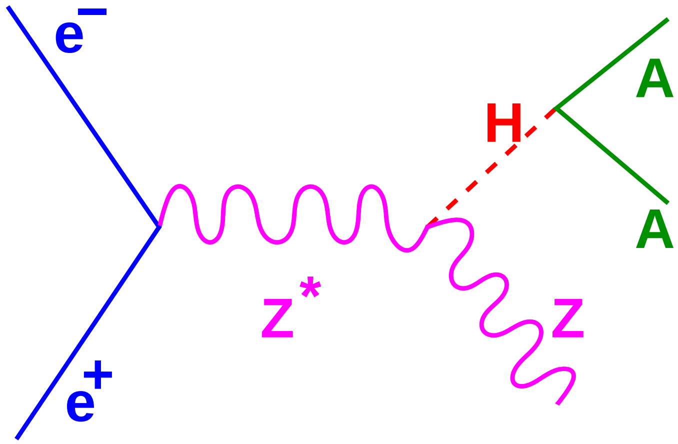
Low m_A, high m_h

Initially triggered by

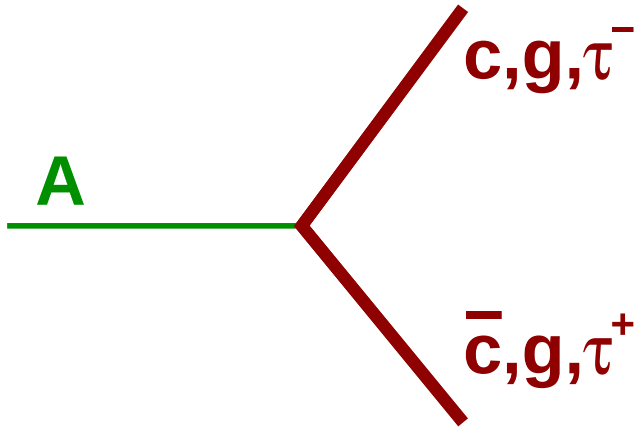


Problematic region

Higgs signature

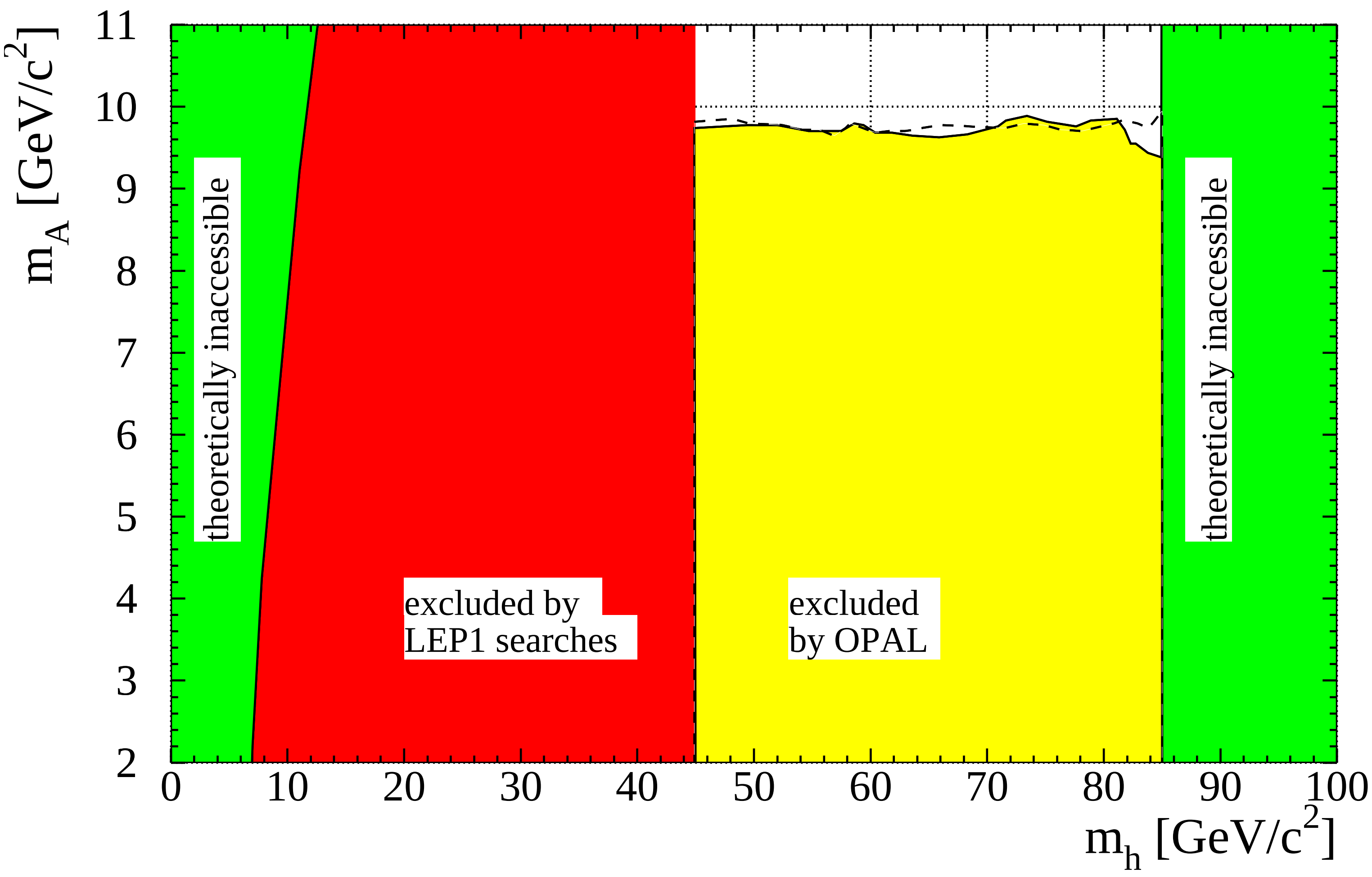


m_h large, $m_A < 10$ GeV



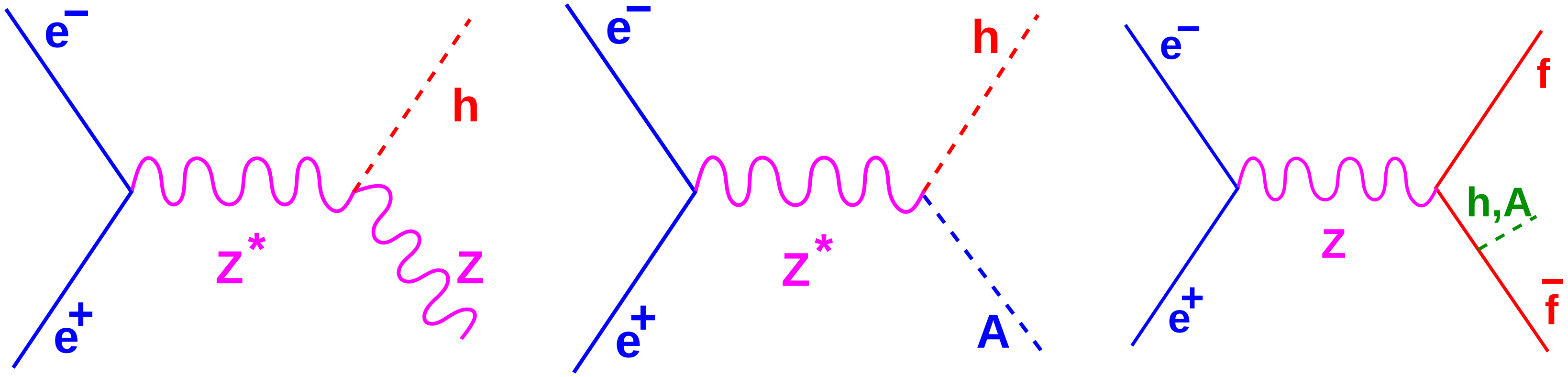
Highly boosted A $\Rightarrow$ 1 jet-like decay

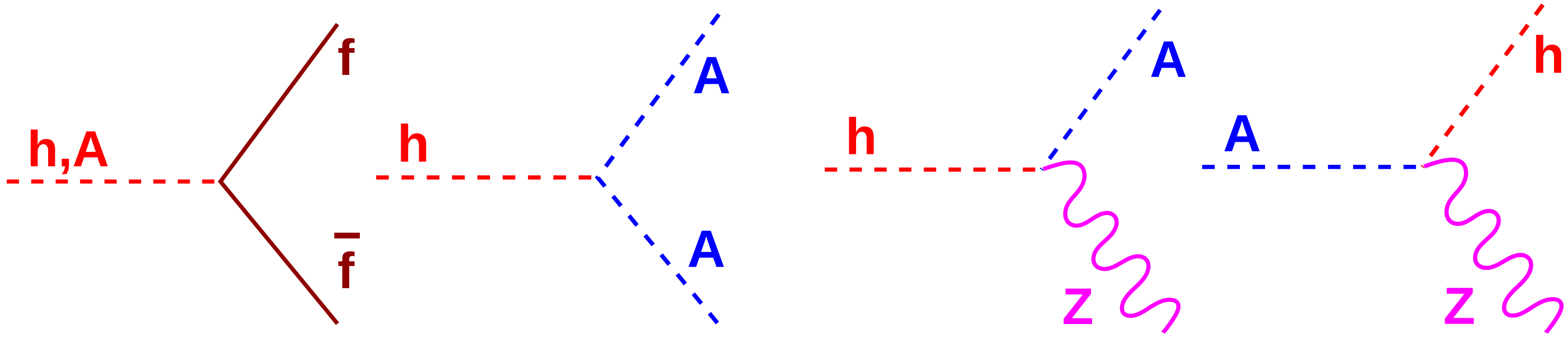
OPAL: No excess observed



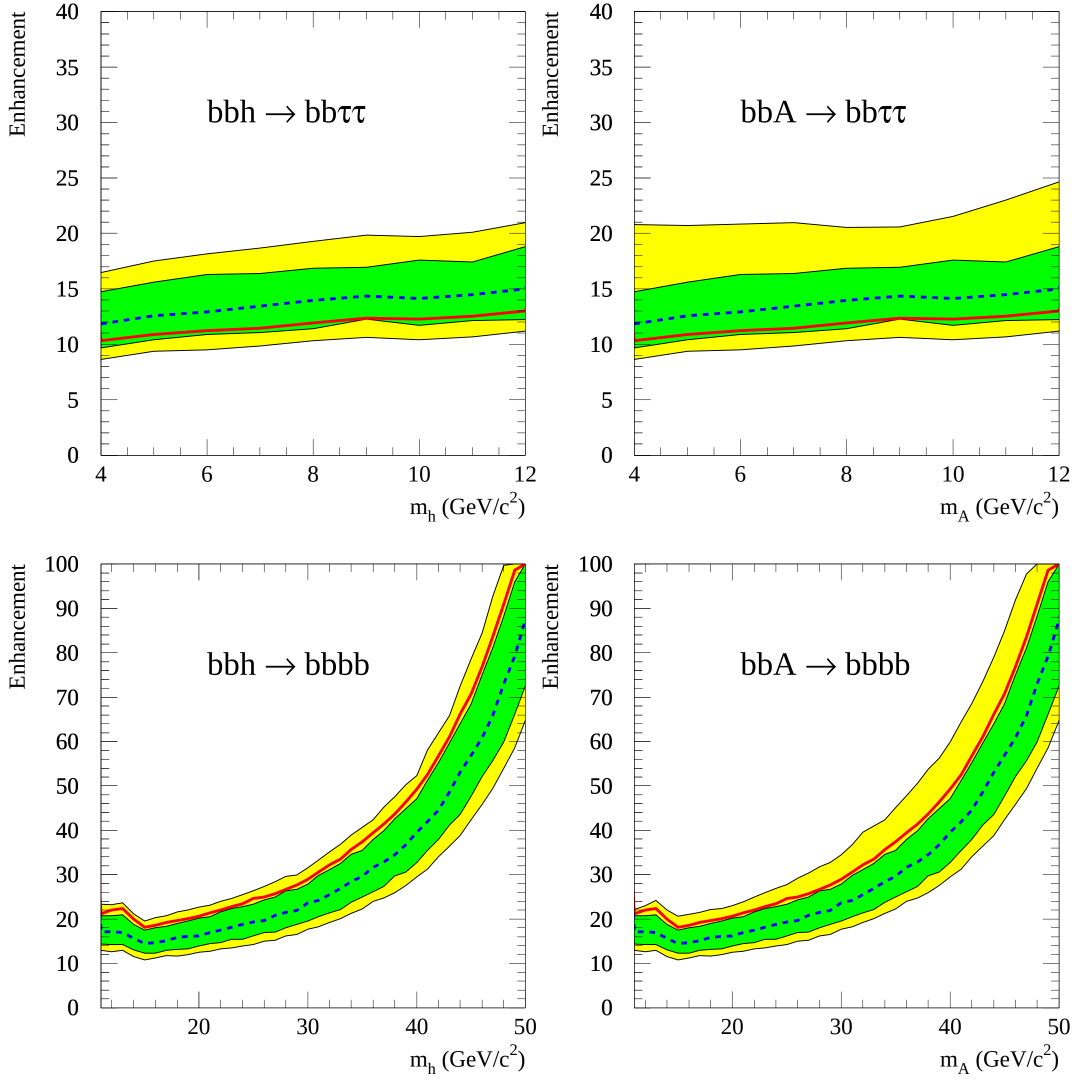
Most of the accesible parameter space excluded

Can we do it better? Two Higgs Doublet models



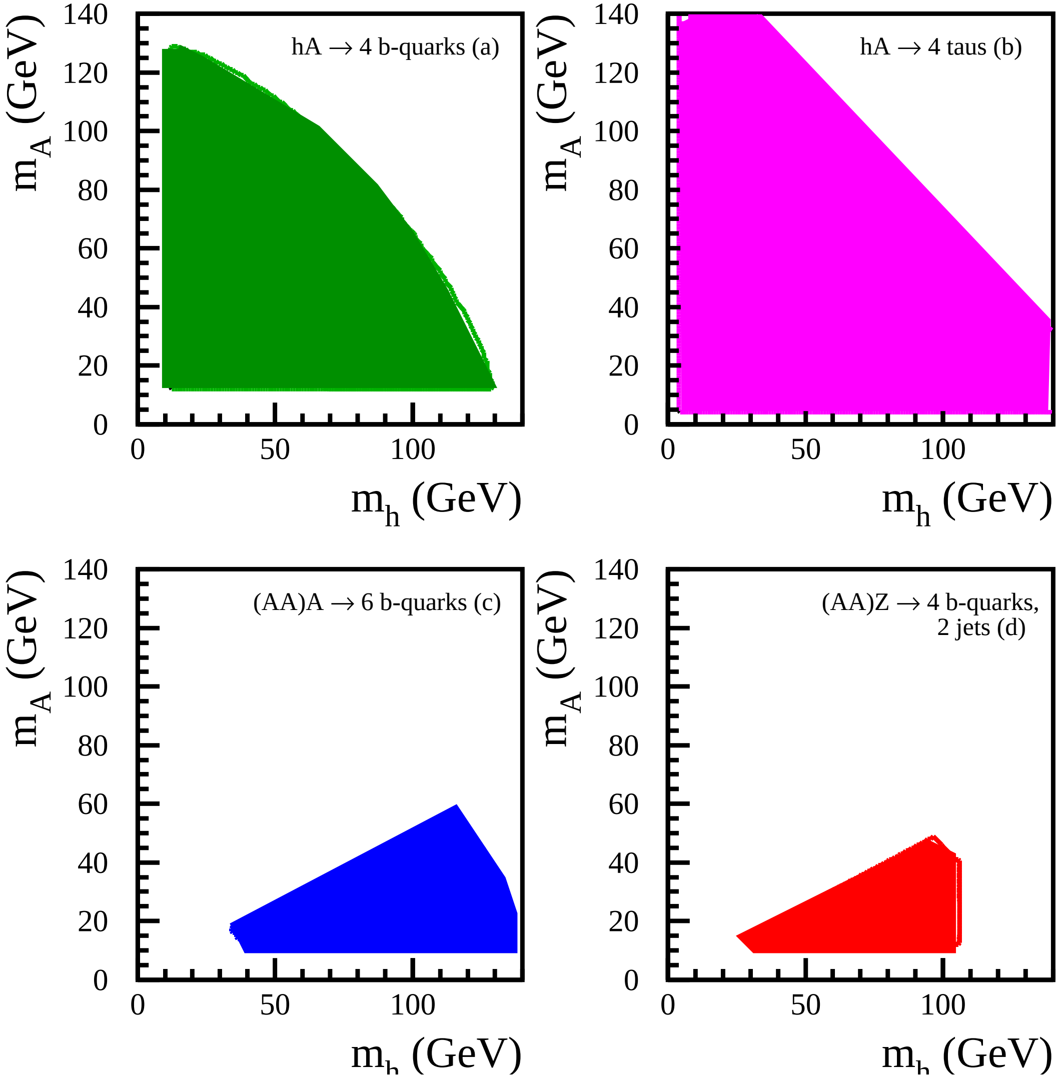


Upper bounds in terms of σ/σ_{ref}

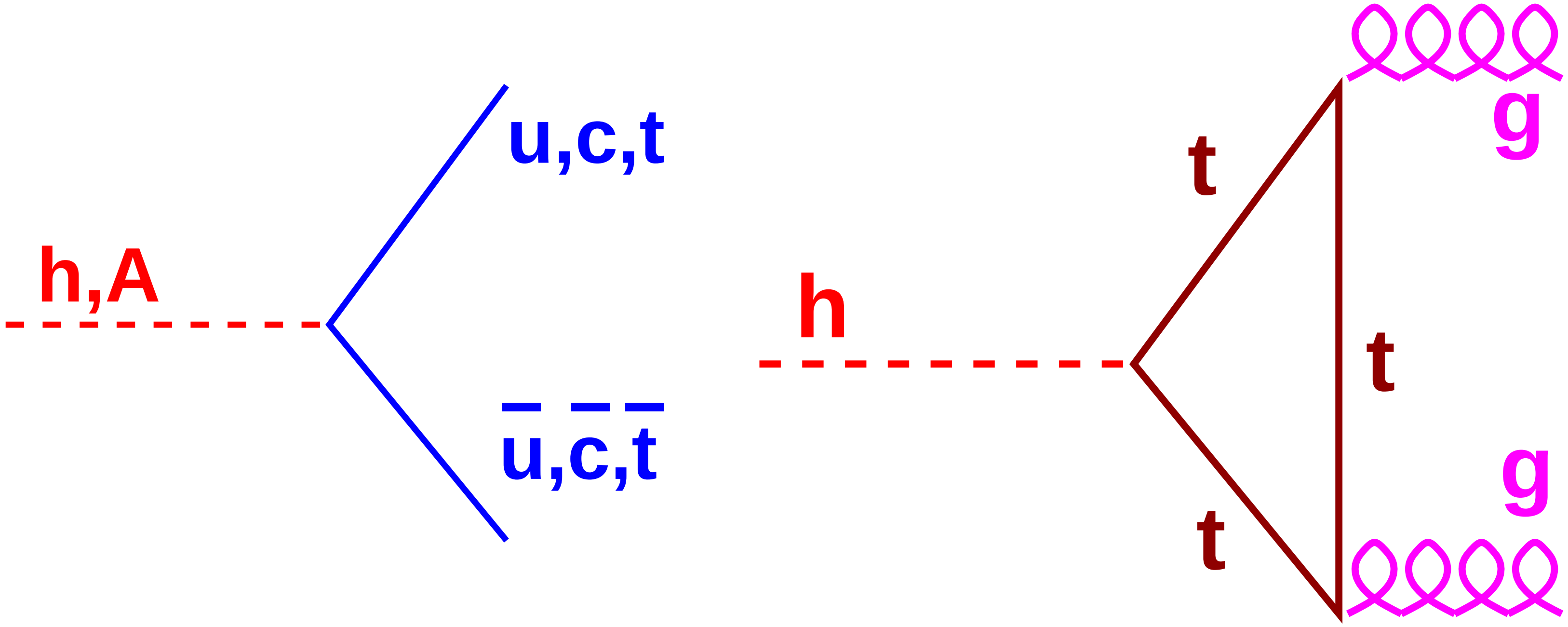


DELPHI: Model-independent 2HDM searches: $e^+e^- \to hA$, $e^+e^- \to hZ$

95% CL excluded regions for $\sigma/\sigma_{ref} = 1$

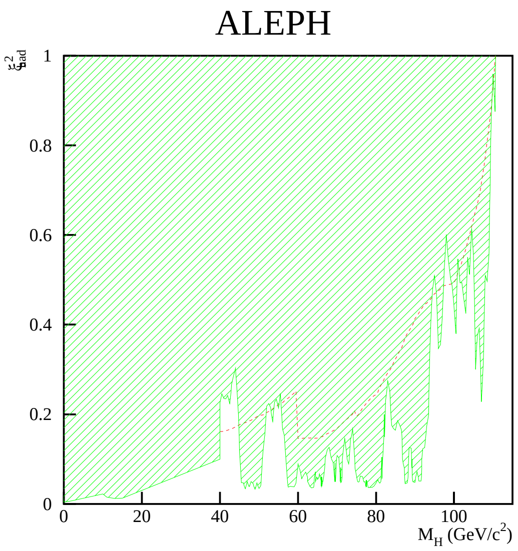


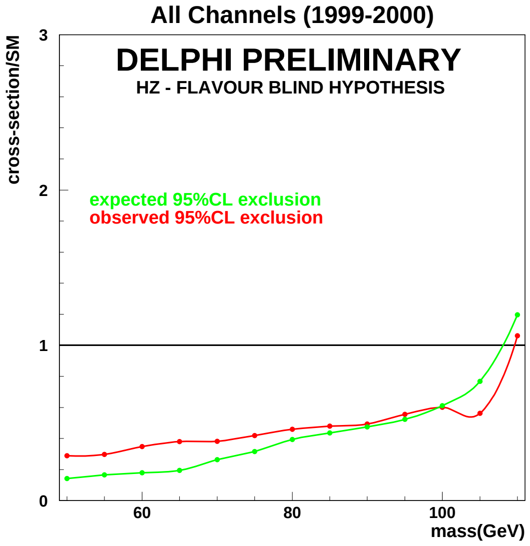
$H \to b\bar{b}$ is really dominant?

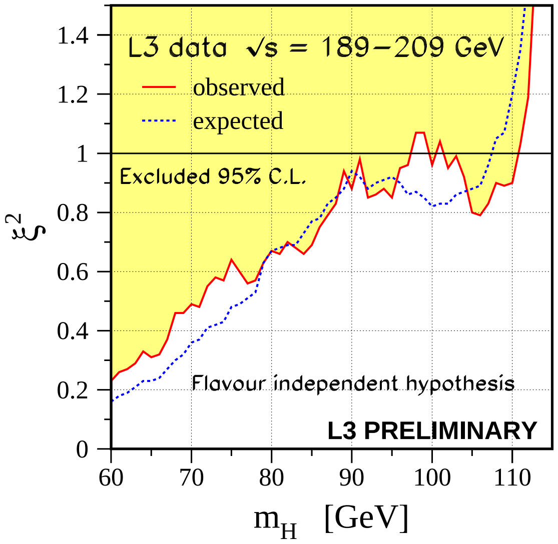


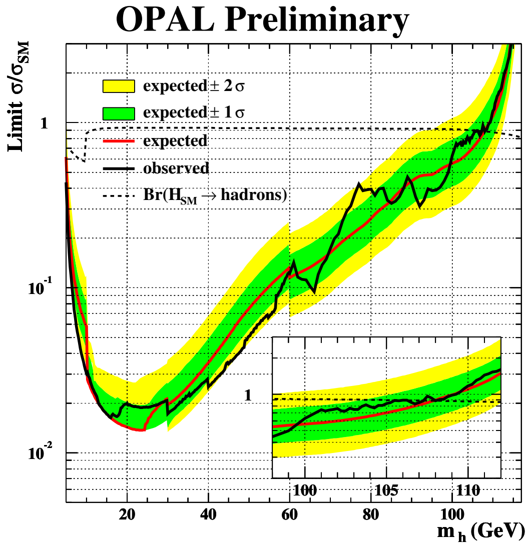
- Main assumption: Higgs decays hadronically
- Main change in the studies: no b-tagging requirements

"Flavour-independent" searches: Results



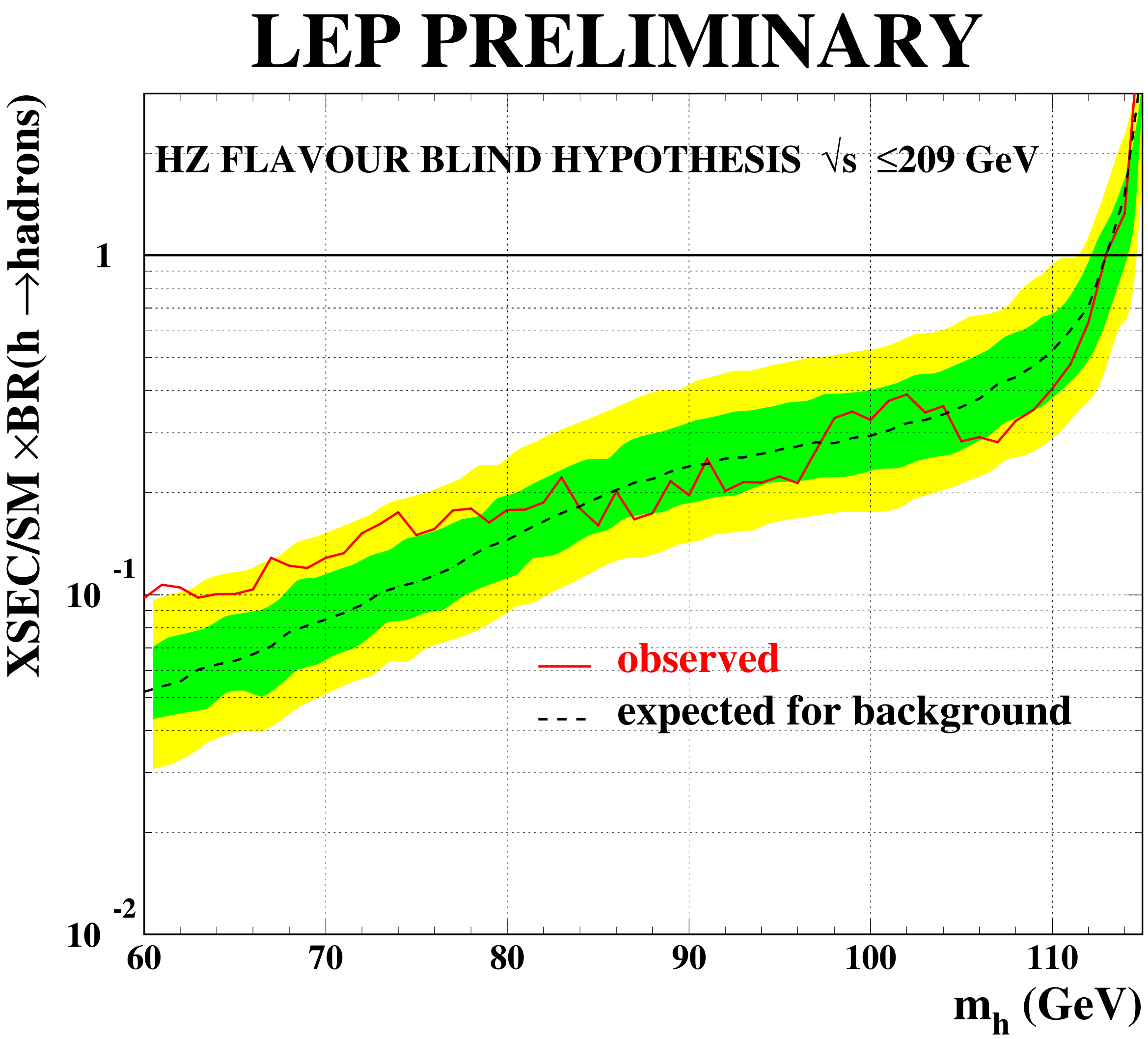






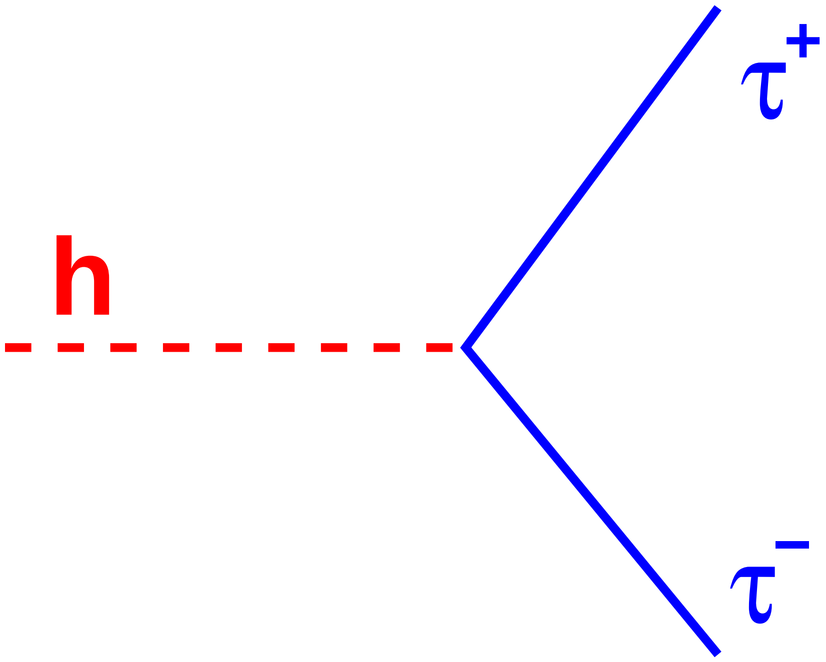
Similar sensitivities for all four LEP experiments

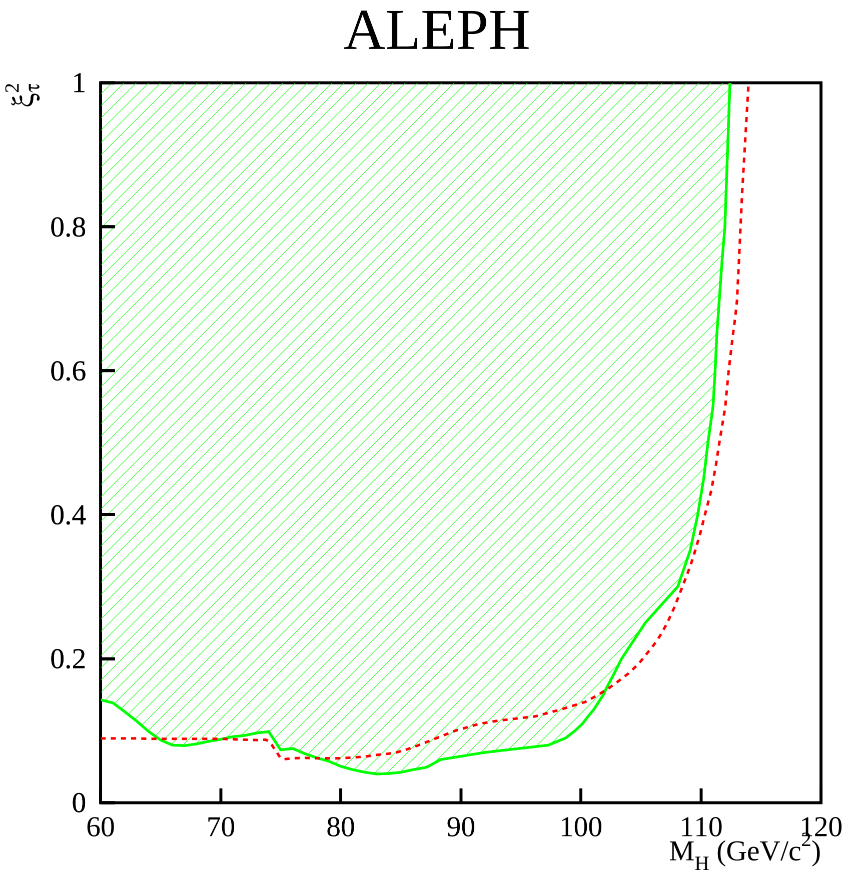
“Flavour-independent” searches: LEP Combined limits



$m_{\rm H} > 113$ GeV at 95% CL

"Flavour-independent" searches: do not forget the τ





$m_{\mathrm{H}} > 109.1$ GeV at 95% CL (ALEPH)

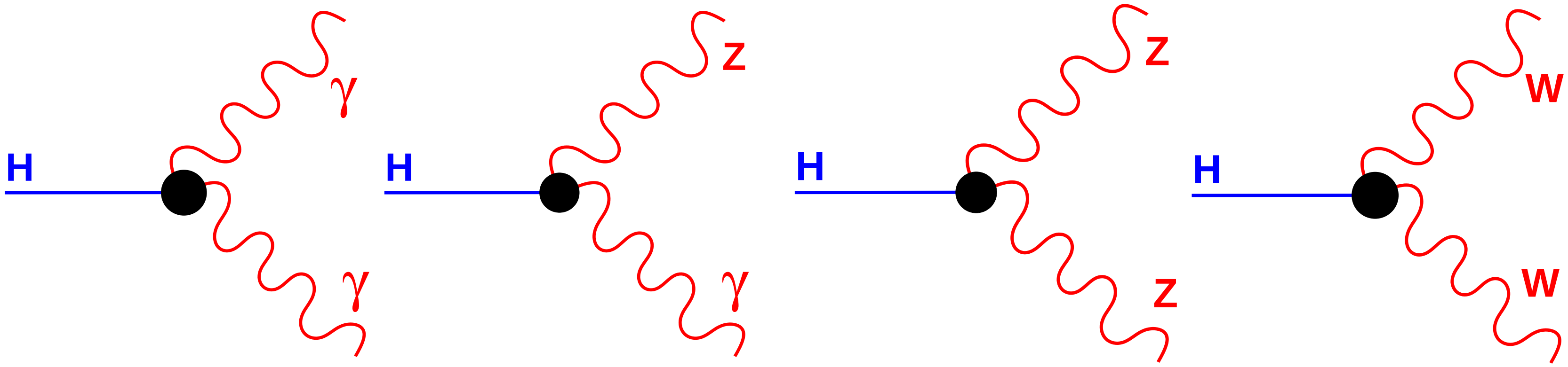
(100% BR into $\mathrm{q\bar{q}}$ or $\tau^+\tau^-$, SM production)

Higgs deviations from the SM from $\Lambda \gg \sqrt{s}$

- If the SM is an approximately correct description of Nature, the "true theory" from a new physics scale Λ looks at low energies like (flavour violations are neglected):

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_{n=6}^{\infty} \frac{1}{\Lambda^{n-4}} \sum_j \mathcal{O}_{nj}$$

- Already at dimension 6 some CP conserving anomalous HVV couplings, not excluded by LEP1 or lower energy experiments, may appear:



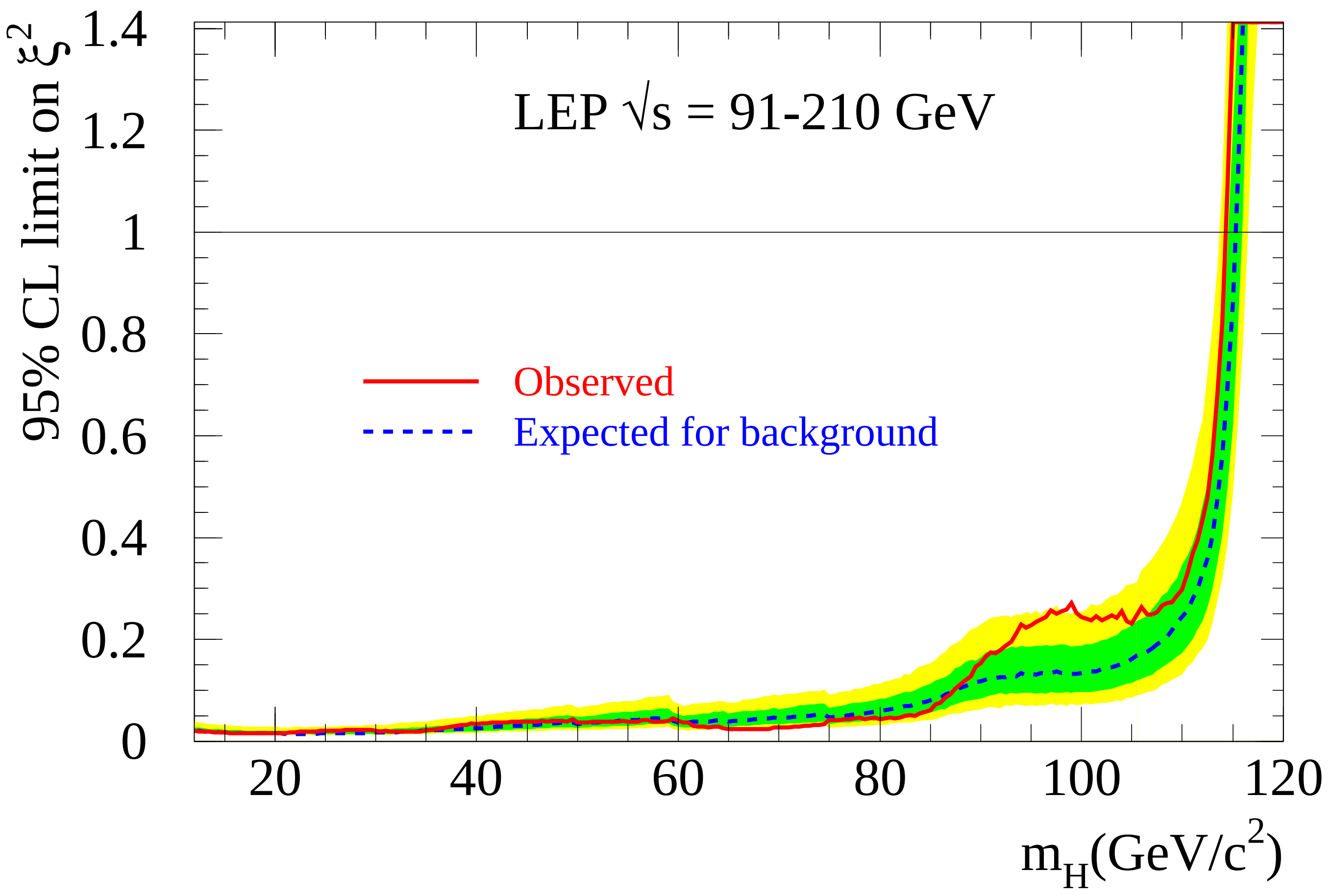
$$\mathcal{L} = \mathcal{L}_{SM} + g_{\mathrm{H}\gamma\gamma}\ \mathrm{H A}_{\mu\nu}\mathrm{A}^{\mu\nu} \ + \ g^{(1)}_{\mathrm{HZ}\gamma}\ \mathrm{A}_{\mu\nu}\mathrm{Z}^{\mu}\partial^{\nu}\mathrm{H} \ + \ g^{(2)}_{\mathrm{HZ}\gamma}\ \mathrm{HA}_{\mu\nu}\mathrm{Z}^{\mu\nu}$$

$$+ \ g^{(1)}_{\mathrm{HZZ}}\ \mathrm{Z}_{\mu\nu}\mathrm{Z}^{\mu}\partial^{\nu}\mathrm{H} \ + \ g^{(2)}_{\mathrm{HZZ}}\ \mathrm{HZ}_{\mu\nu}\mathrm{Z}^{\mu\nu} \ + \ g^{(3)}_{\mathrm{HZZ}}\ \mathrm{HZ}_{\mu}\mathrm{Z}^{\mu} \ + \ \ldots$$

Anomalous Higgs coupling ξ (Grzadowski and Wudka, Phys.Lett.B364 (1995)49)

Effect: Renormalization of the Higgs field, do not change BRs

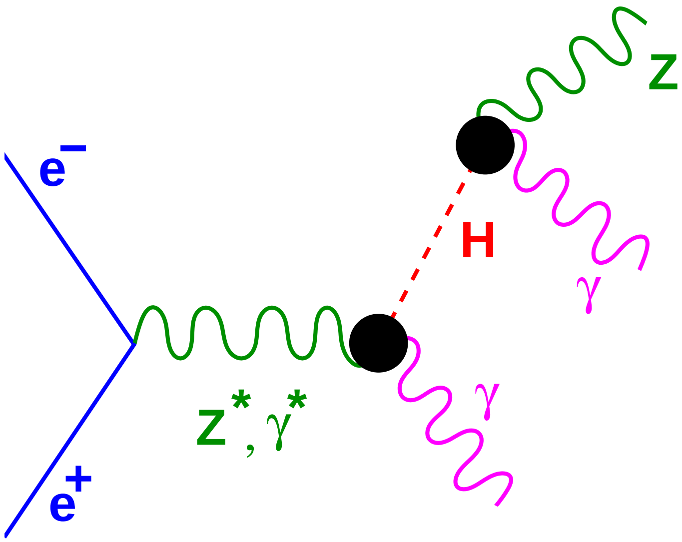
Search: reinterpretation of SM Higgs searches ($\xi^2 = \sigma^{ZH}/\sigma^{ZH}_{SM}$)

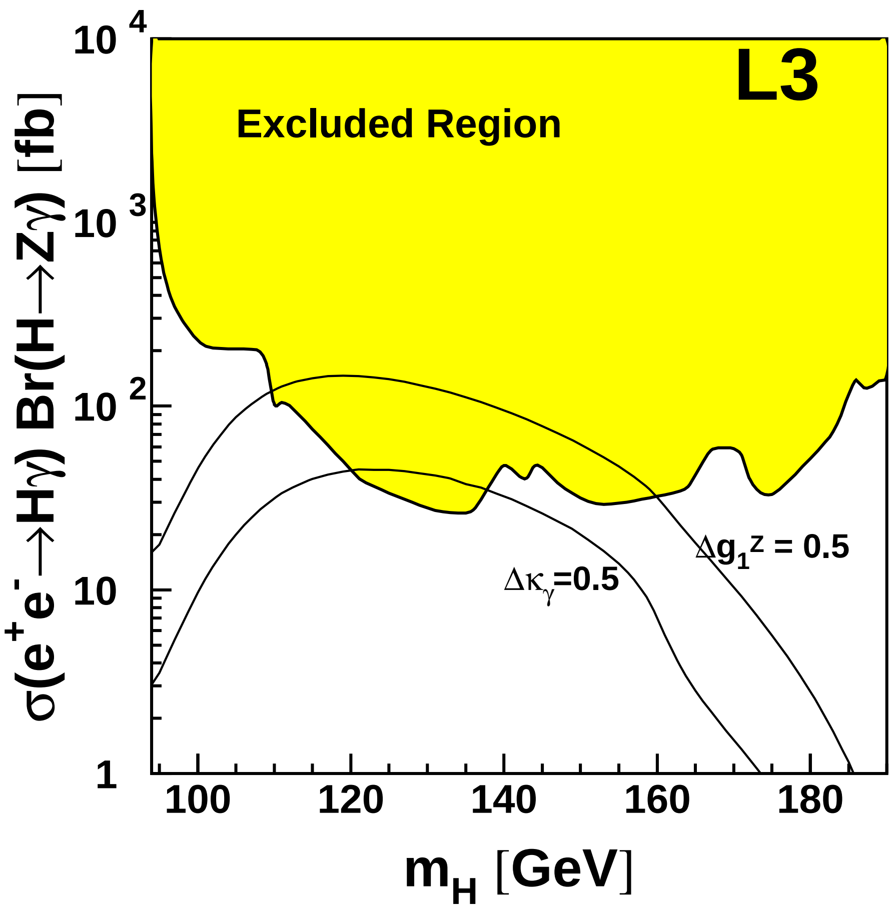


Anomalous Higgs couplings Δg_1^Z, $\Delta\kappa_\gamma$ *(usual WWV couplings)*

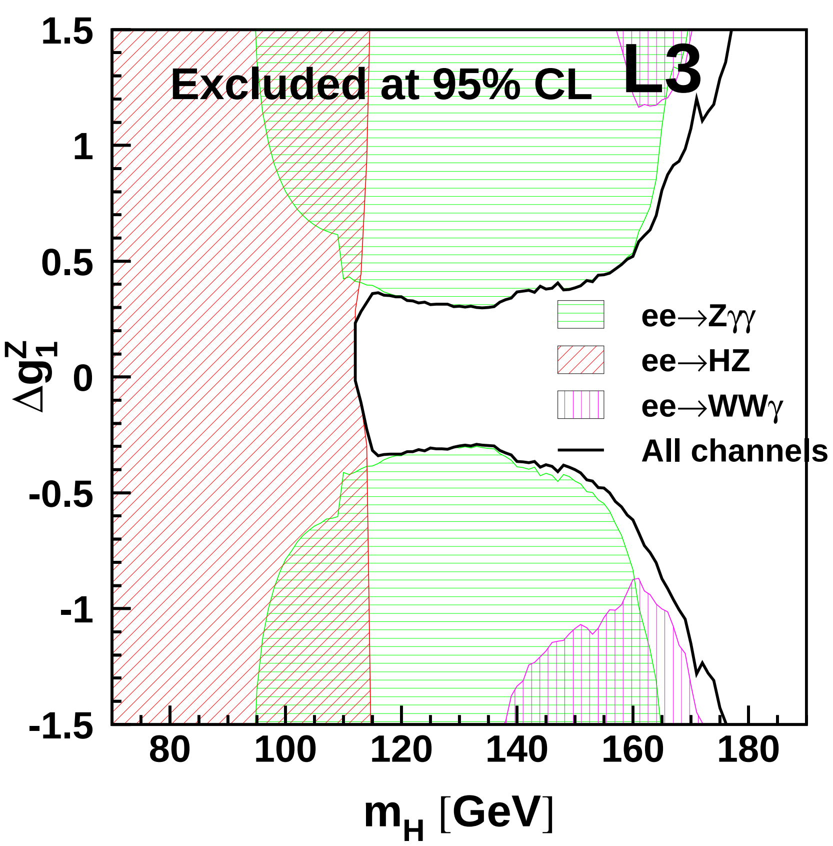
Effect: Change in HWW, HZZ, HZγ couplings

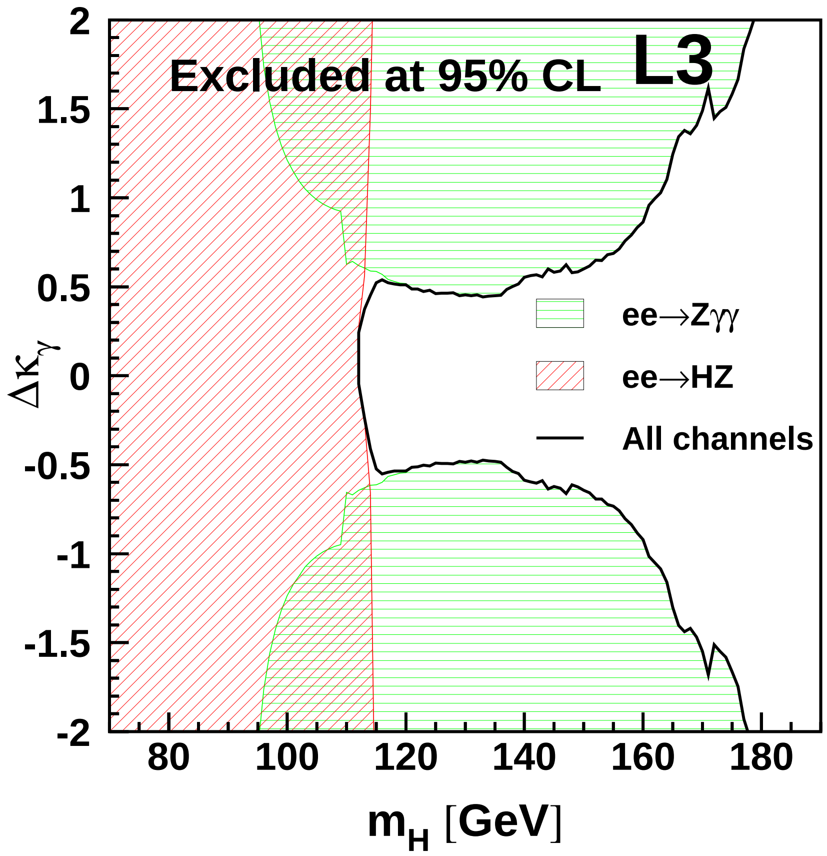
Searches: $e^+e^- \rightarrow HZ$ and $e^+e^- \rightarrow H\gamma \rightarrow Z\gamma\gamma$





Anomalous Higgs couplings Δg_1^Z, $\Delta\kappa_\gamma$: NO EXCESS



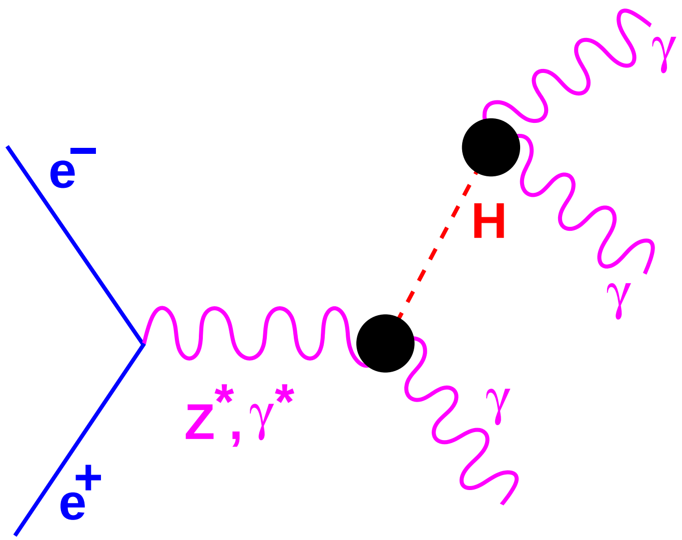


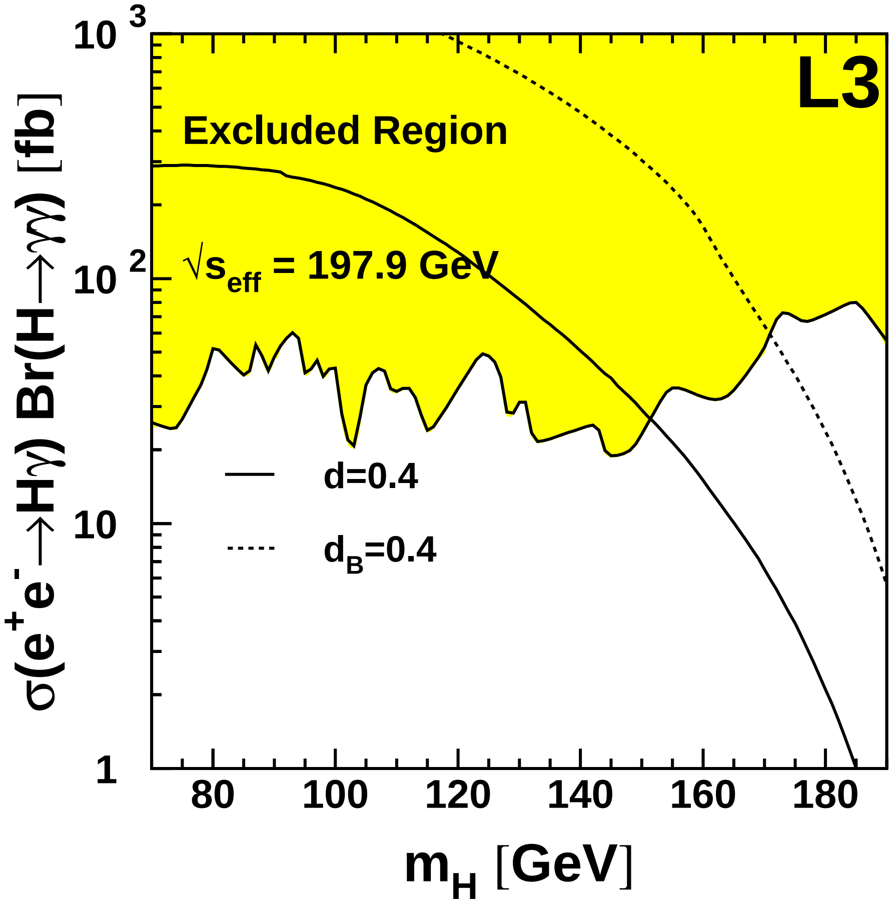
$| \Delta g_1^Z |, | \Delta\kappa_\gamma | \lesssim 0.5$ at 95% CL , $m_H \lesssim 160$ GeV

Anomalous Higgs couplings d, d_B *(Gounaris et al., Nucl.Phys.B459 (1996)51)*

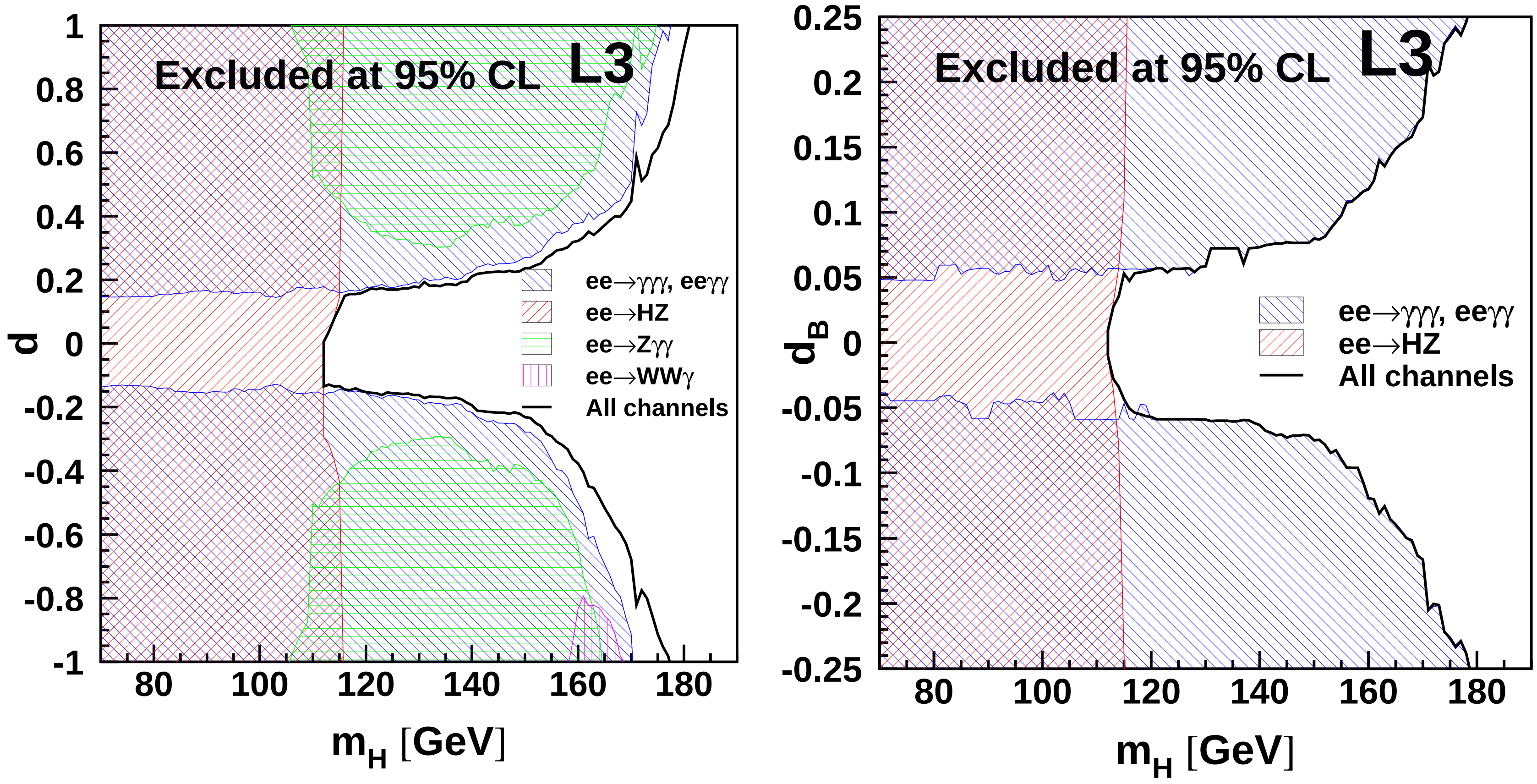
Effect: Change everything, but mostly $H\gamma\gamma$ and $HZ\gamma$ couplings

Searches: $e^+e^- \to H\gamma$, $\gamma\gamma \to H$, . . . , with $H \to \gamma\gamma$ or $H \to Z\gamma$



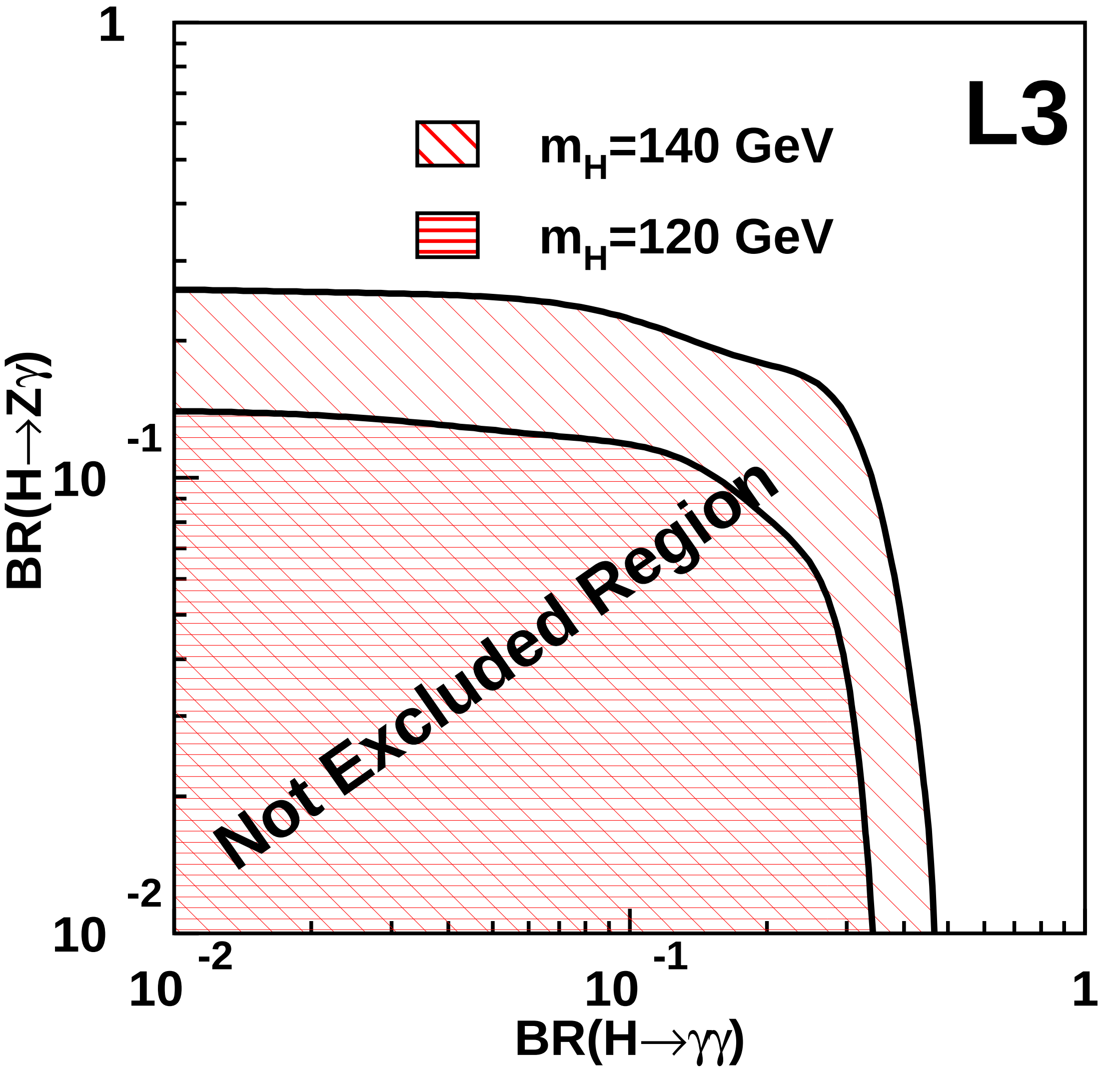


Anomalous Higgs couplings d, d_B, NO EXCESS



$| \, d \, | \lesssim 0.1, | \, d_B \, | \lesssim 0.05$ at 95% CL , $m_{\mathrm{H}} \lesssim 160$ GeV

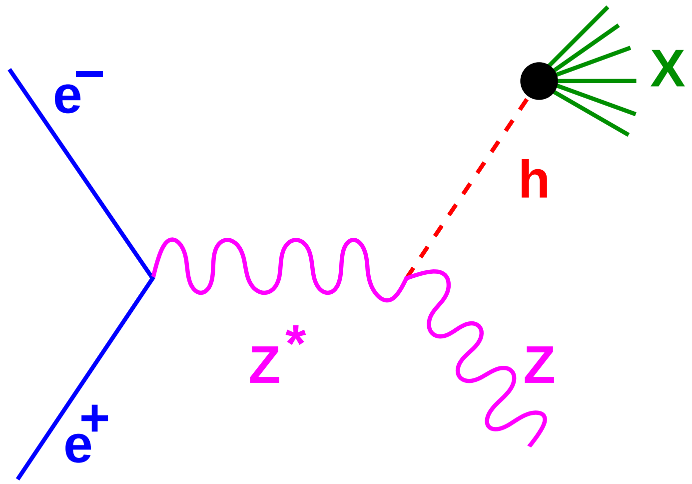
Alternative interpretation of d, d_B limits



Limits to $Br(\mathrm{H} \to \gamma\gamma)$ and $Br(\mathrm{H} \to \mathrm{Z}\gamma)$ in the region of LHC interest

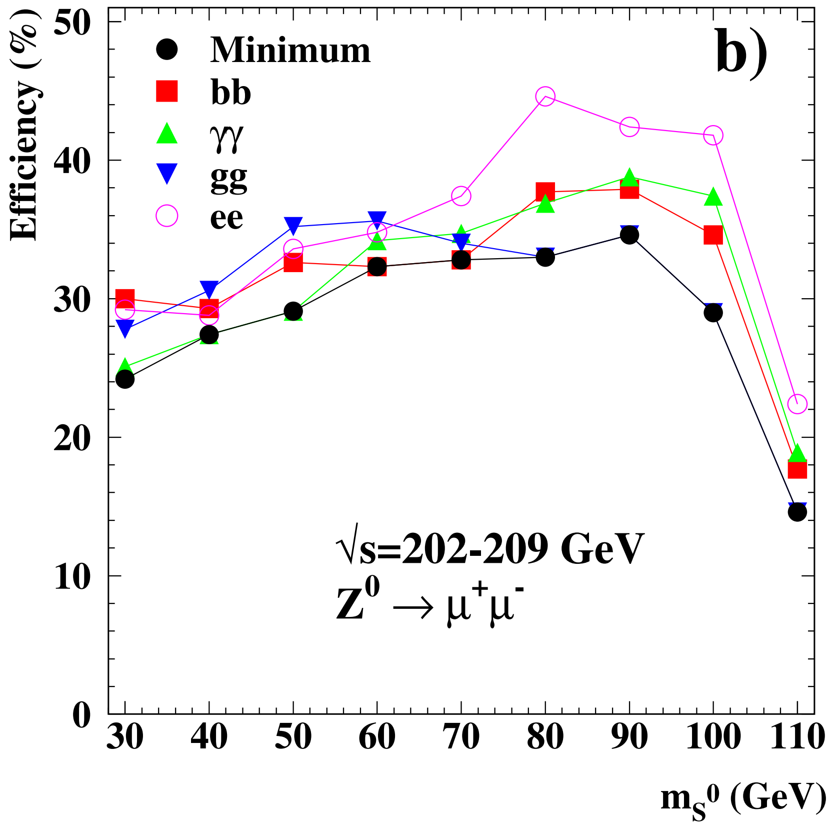
“Decay-independent” searches

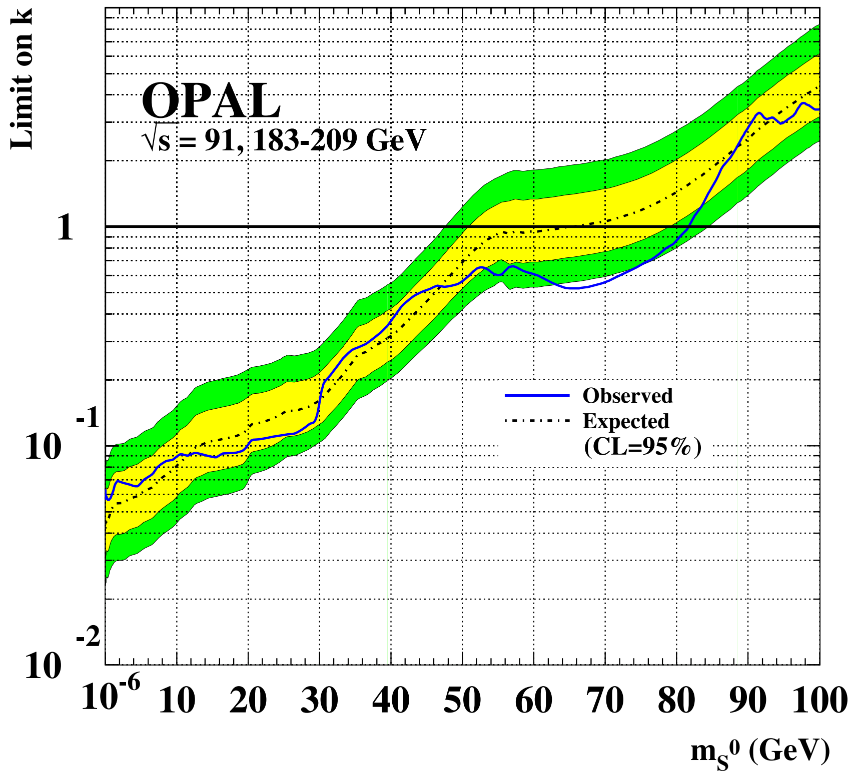
And if we do not want to assume anything ...



- Aim: Efficiency should not depend on what happens on the Higgs side
- How: Use only $\mathrm{Z} \to \mathrm{e}^+\mathrm{e}^-$, $\mathrm{Z} \to \mu^+\mu^-$, maybe $\mathrm{Z} \to \nu\bar{\nu}$

OPAL: No excess found



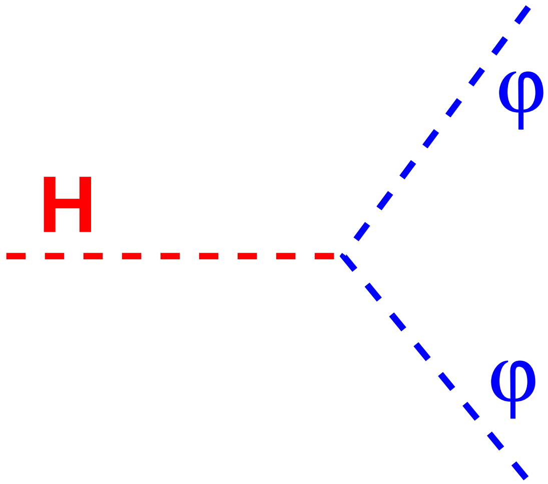


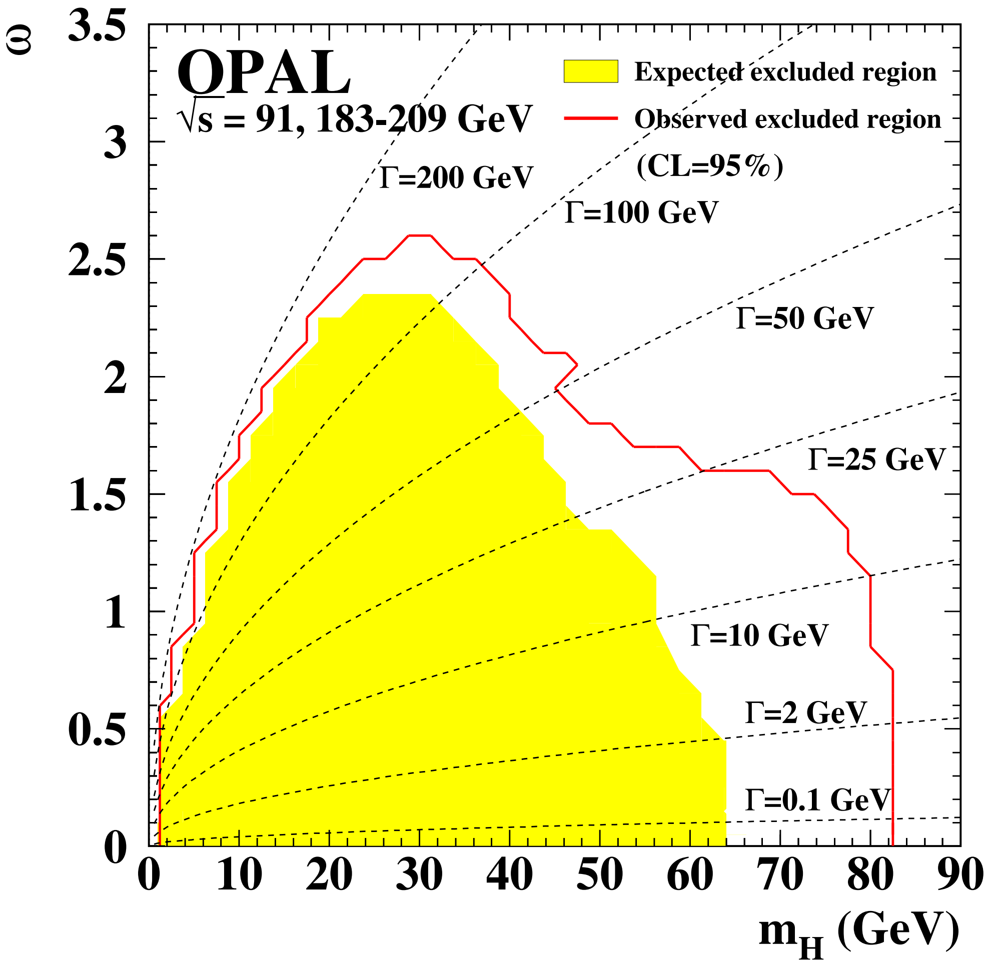
For $\sigma/\sigma_{SM} = 1$, $m_{\mathrm{H}} > 81$ GeV at 95% CL

And if the Higgs is too wide . . .

- Stealthy Higgs Model: Higgs singlets (phions) do not interact with matter
- But they can interact with the SM Higgs doublet:

$$\Delta\Gamma_{\rm H} \rightarrow \frac{\omega^2 v^2}{32\pi m_{\rm H}^2},\ N_{phions} \rightarrow \infty$$





For $m_{\rm H} \approx \Gamma_{\rm H}$, $m_{\rm H} \gtrsim 50$ GeV at 95% CL

Summary

- Big efforts by the LEP Collaborations to be sure that we are not missing ANY Higgs

- Interesting studies in different directions by the different Collaborations

- For the moment, wherever we look for:
  NO EVIDENCE FOR A FUNDAMENTAL SCALAR