# Search for Neutral Higgs Bosons of the MSSM in $e^+e^-$ Interactions at $\sqrt{s}$ = 130 - 189 GeV

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## L3 Collaboration

## Outline

- Introduction
- Production Mechanisms and Decay Modes
- Search Topologies and Background Processes
- Conclusion and Present Limit on $M_h$ and $M_A$

Special Thanks to J. Branson, A. Dominguez, I. Fisk and A. Kopp

# INTRODUCTION

- **MSSM Higgs Sector**

  . **Two Higgs Doublet Model**

  $\Rightarrow$ **5 Physical Higgses: $h^0$,$A^0$,$H^0$,$H^{\pm}$**

  . **Governed at the Tree Level: $M_A$, $\tan\beta$**

  . **with Radiative Corrections enters: $A_0$, $\mu$, $M_2$, $m_0$**

- **Theoretical Constraint on $M_h$**

  **Tree Level:**

$$M_h < M_Z cos(2\beta)$$

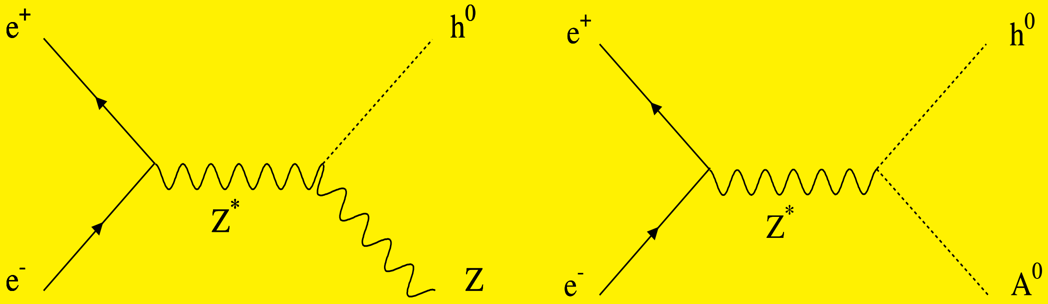
  **Radiative Corrections:**

$$M_h^2 \leq M_Z^2 cos^2(2\beta) + \frac{3g^2 M_t^4}{8\pi^2 M_W^2} Ln \frac{M_{\tilde{t}_1}^2 M_{\tilde{t}_2}^2}{M_t^4} + \ldots$$

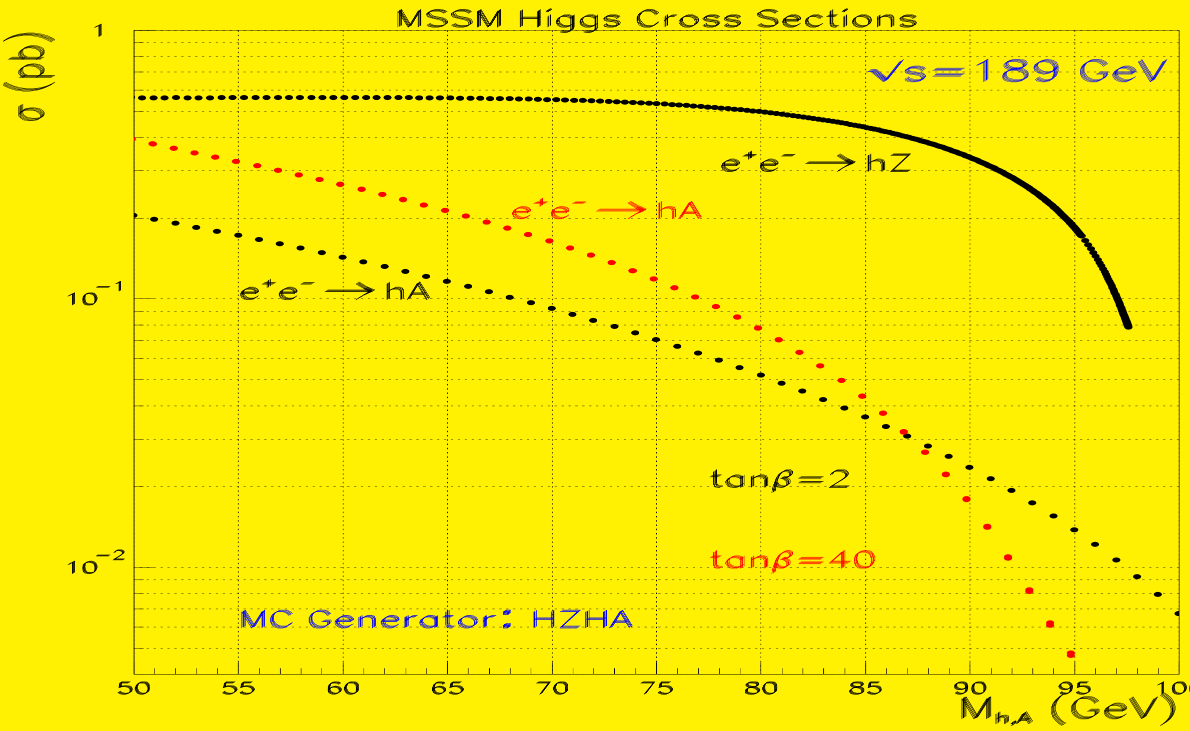
$$\Rightarrow \mathrm{M_h} \leq \textbf{136 GeV}$$

# HIGGS PRODUCTION AND DECAY MODES

- **Production**




$$\begin{cases} \sigma(e^+e^- \to hZ) = \sin^2(\beta-\alpha) \times \sigma(e^+e- \to H_{SM}Z) \\ \sigma(e^+e^- \to hA) = \cos^2(\beta-\alpha) \times \bar{\lambda} \times \sigma(e^+e^- \to H_{SM}Z) \end{cases}$$

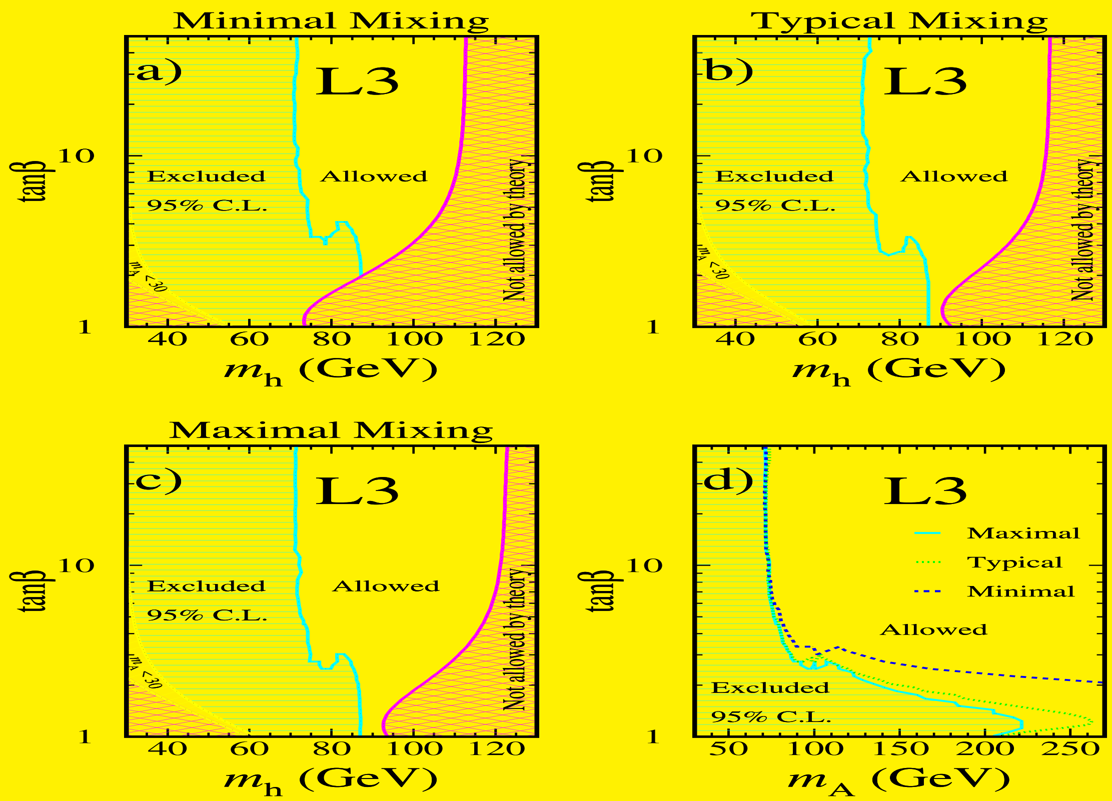



- **Decay Modes**

$$\begin{cases} h \to b\bar{b}, \tau^\pm\tau^\mp \\ A \to b\bar{b}, \tau^\pm\tau^\mp \end{cases} \qquad \begin{cases} BR(h, A \to b\bar{b}) \approx 85\% \\ BR(h, A \to \tau^\pm\tau^\mp) \approx 8\% \end{cases}$$

# PREVIOUS LIMITS FROM DIRECT SEARCHES

- **L3 Limits for 130$\leq \sqrt{s} \leq$183 GeV**




**At 95% CL $M_h$ >70.7 GeV and $M_A$ >71.0 GeV**

- **L3 Data Samples**

| Year | $\sqrt{s}$ (GeV) | $\int \mathcal{L}dt$ (pb$^{-1}$) |
|---|---|---|
| 1995 | 130-136 | ≈6 |
| 1996 | 161 | 10.7 |
| 1996 | 172 | 10. |
| 1997 | 183 | 55.3 |
| 1998 | 189 | 176.4 |

# ANALYSIS PROCEDURES

- **MSSM Scan**

  . **Max. Stop Mixing Definition:**
  $A_0 = \sqrt{6}$ TeV, $\mu = -100$ GeV, $M_2 = m_0 = 1$ TeV

  . **Scan:**

$$\begin{cases} 1 \leq \tan\beta \leq 50, \ (m_t = 175 \text{ GeV}) \\ 30 \leq m_{\text{A}} \leq 1000 \text{ GeV}, \end{cases}$$

  . **Min. and typical mixing hypothesis to be included**

- **hZ Analysis**

  . **Results in the** $q\bar{q}\nu\bar{\nu}$ and $q\bar{q}\ell^+\ell^-$ ($\ell^\pm = e^\pm$ or $\mu^\pm$) **topologies are taken from SM Higgs search**

- **hA Analysis**

  . **Two topologies: hA**$\rightarrow b\bar{b}b\bar{b}$ **and hA**$\rightarrow b\bar{b}/\tau\tau$**, but no Z mass constraint and higher b-tag**

- **Analysis Steps**

  . **Preselection: high multiplicity hadronic events**

  . **Optimized Cuts for each Topologies**

  . **Final Discriminant: function of mass hyp. and ratio of hZ to hA production**

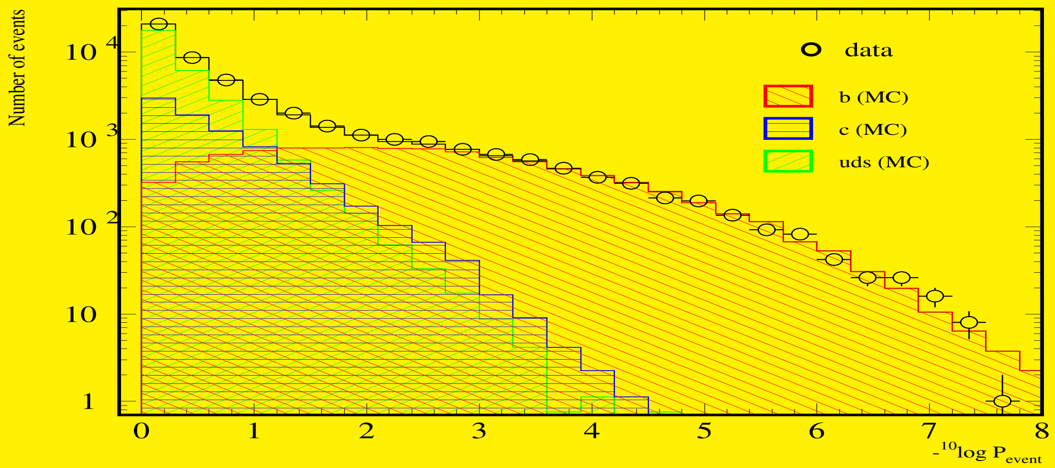
  . **Final discriminant distributions** $\rightarrow$ **inputs for limit calculation**

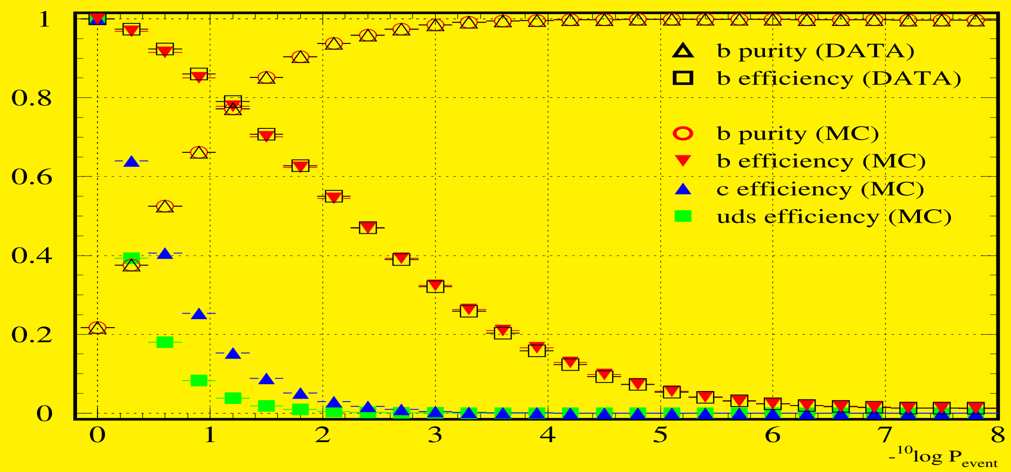
- **NN B-Tagging**

  . **Crucial in the discriminant calculation**

  . **Inputs: tracks lifetime CL, jets shape variables and identified leptons in jet**

  . **Output: b-tag for each hadronic jet, combined into a event b-tag**




**L3 NN B-Tag Performance on Z-peak Data**

# SEARCH TOPOLOGIES AND BACKGROUND PROCESSES

## 4 Jets

- **Signal: hZ$\rightarrow b\bar{b}q\bar{q}$ and hA$\rightarrow b\bar{b}b\bar{b}$**

- **Background Processes**

  $\mathrm{W^+W^-,\ q\bar{q},\ ZZ,\ e^{\pm}\nu_e q\bar{q}',\ e^+e^-q\bar{q}}$

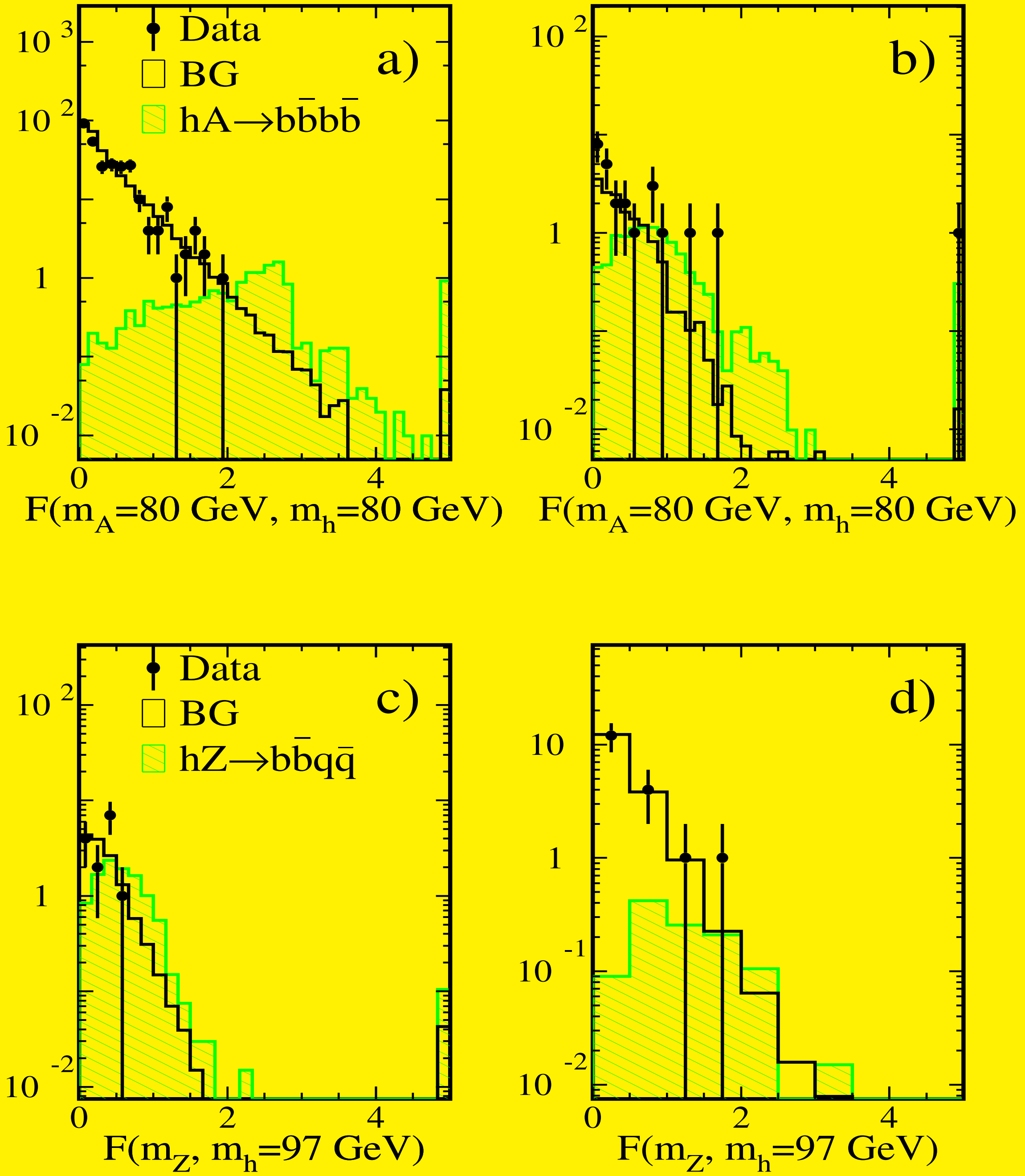
- **Analysis**

  **. Preselection,... , Kinematical 4C fit**

  **. hZ and hA Cuts Optimization: event b-tag, Y$_{34}$, mass $\chi^2$, N$_{TR}$ and jet based kinematical variables**

  **. $\chi^2$ proba. on mass hyp. and $\sigma_{hZ}/\sigma_{hA} \Rightarrow$ 2 categories: hZ-like or hA-like events**

  **. Final discriminant: weighted combination of proba. b-tag and mass $\chi^2$**




**Final discriminants**

# 2 Taus + 2 Jets

- **Signal:** $\mathrm{hA} \to \mathrm{b\bar{b}}/\tau\tau$ and $\mathrm{hZ} \to \mathrm{b\bar{b}}\tau\tau$ or $\tau\tau\mathrm{q\bar{q}}$

- **Background Processes**

  $\mathrm{W^+W^-}$, ZZ, $\mathrm{e^+e^-q\bar{q}}$

- **Analysis Procedure: hZ or hA**

  **. Two selections: $\tau$-ID or jet based selections**

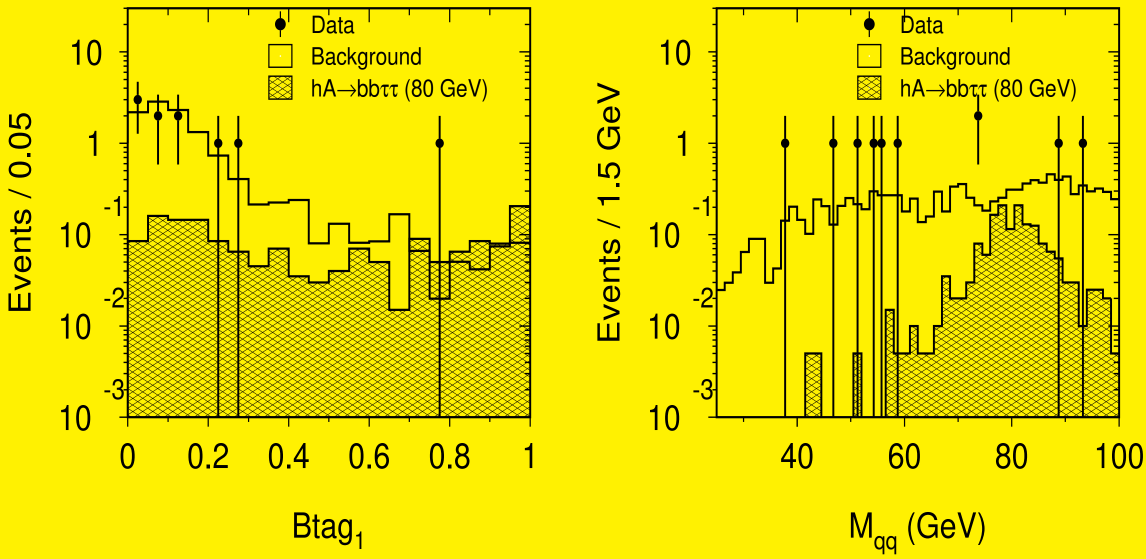
  **. Common preselection: missing energy, high multiplicty events**

  **missing energy, high multiplicty events with 2 hard $\tau$ and 2 hadronic jets**

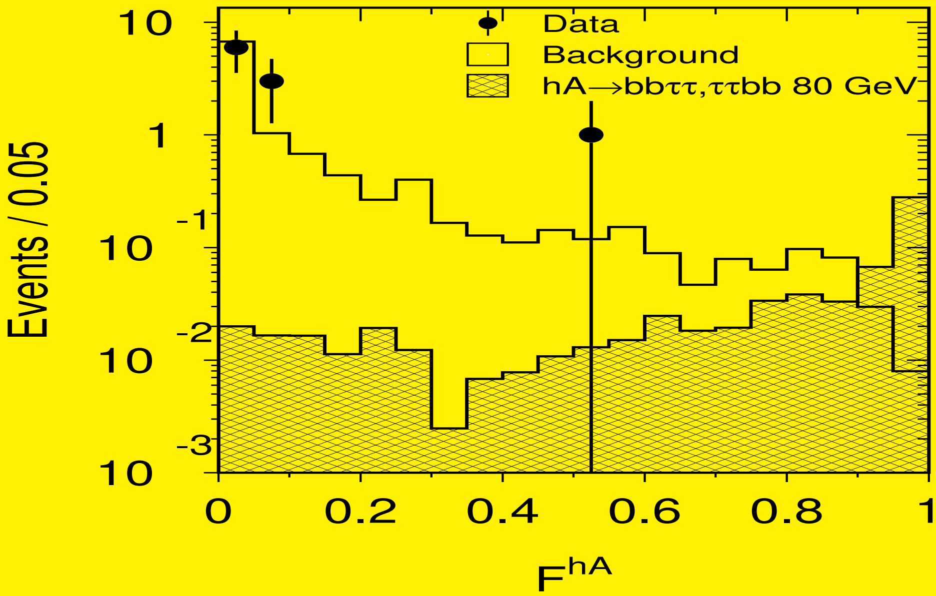
  **. Kinematic 4C fit with 25$< \mathrm{M}_{\tau\tau}$ or $\mathrm{M_{jj}} <$100 GeV**

  **. Final discriminant: likelihood combining b-tag with M$_{\tau\tau}$ or with M$_{jj}$**

  **. The events that pass both filters are classified into one of them using the $\sigma_{hZ}/\sigma_{hA}$ info**




**First jet b-tag and rec. dijet mass after kin. fit**
**Events from $\tau$-ID or jet based selection**




**Final discriminant for tau analysis**
**with $\mathrm{M_h}$ =80 GeV and tan$\beta$ =50**

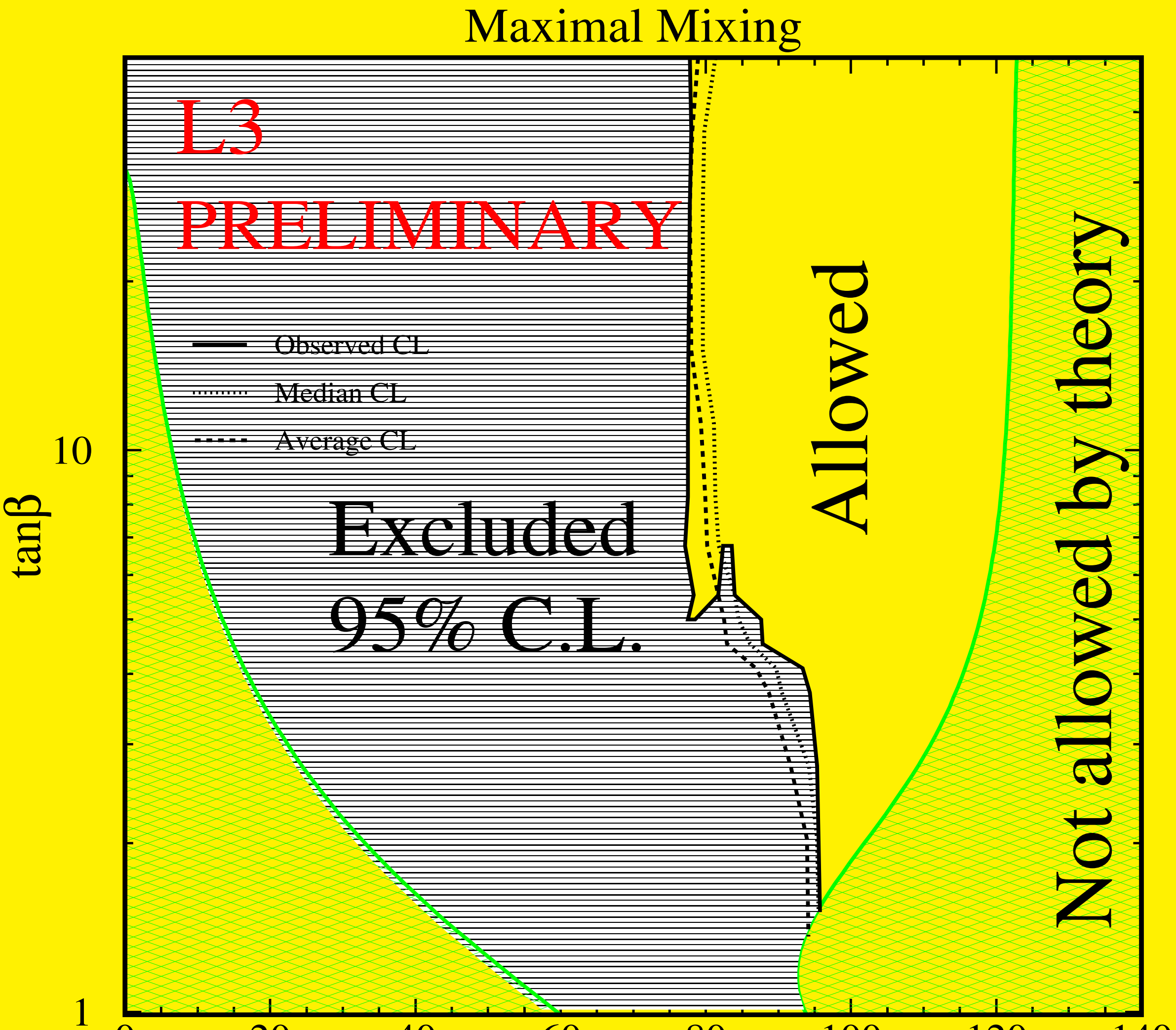
# LIMITS IN THE MAXIMAL STOP MIXING SCENARIO

- **Mass Limits**

  **At 95% CL, M$_h > 77$ GeV and M$_A > 78$ GeV**

  **(Including searches at $\sqrt{s}$=183-189 GeV)**

- **Exclusion Plot in the MSSM**



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# RESULTS FROM THE OTHER LEP COLLABORATIONS

- **ALEPH**
  - . **M**$_h > 80.8$ **GeV**
  - . **M**$_A > 81.2$ **GeV**
- **DELPHI**
  - . **M**$_h > 83.5$ **GeV**
  - . **hM**$_A > 84.5$ **GeV (tan**$\beta >$**0.5)**
- **OPAL**
  - . **M**$_h > 74.8$ **GeV**
  - . **M**$_A > 76.5$ **GeV (tan**$\beta >$**1)**
- **ADLO LEPC Sept. 98**
  - . **M**$_h > 78.8$ **GeV**
  - . **M**$_A > 79.1$ **GeV**

**95**$\%$ **CL Limits (PRELIMINARY)**