MSSM Higgs Searches at LEP

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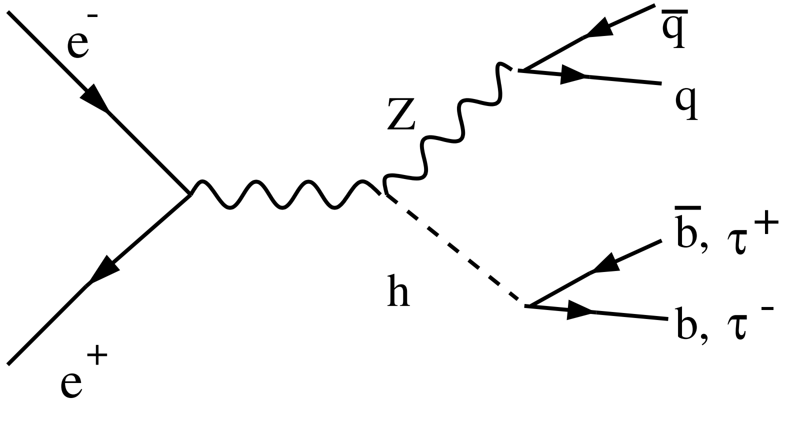
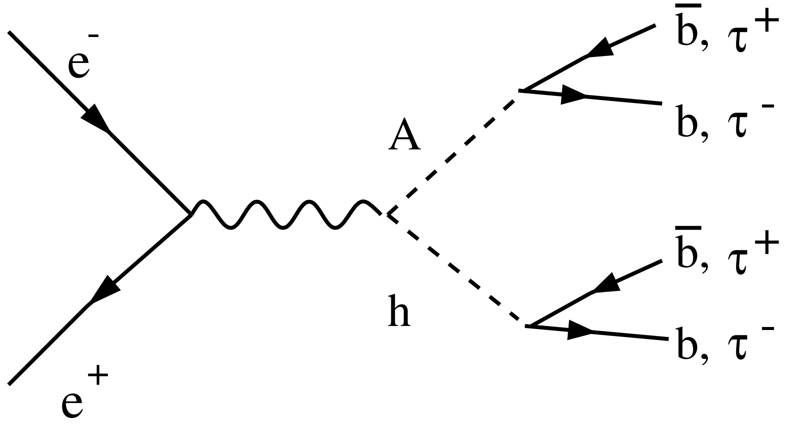
- **Introduction**
- **Production and Decay of the MSSM Higgs Bosons**
- **Strategy of the MSSM Higgs searches using L3 as an example**
- **Results and Interpretations**
- **Combined LEP Results**

ALL THE RESULTS ARE PRELIMINARY

MSSM Higgs Neutral Bosons

MSSM uses 2 doublets in the Higgs sector corresponding to 5 physical scalars:
2 charged and 3 neutral (A CP-odd, h and H CP-even)





Higgsstrahlung

- **Very similar to the SM process**
- **Kinematic Limit at** $(\sqrt{s} - m_Z)$

$$\propto \sin^2(\beta - \alpha)$$

Pair Production

- **The statistics is very important**

$$\propto \cos^2(\beta - \alpha)$$

$\Leftarrow$ Complementary Processes $\Rightarrow$

Relative rates of $e^+e^- \rightarrow \mathrm{h}Z$ **and** $e^+e^- \rightarrow \mathrm{h}A$ **change as** $\mathrm{f}(\tan\beta)$

MSSM Benchmarks

Free parameters of the MSSM:

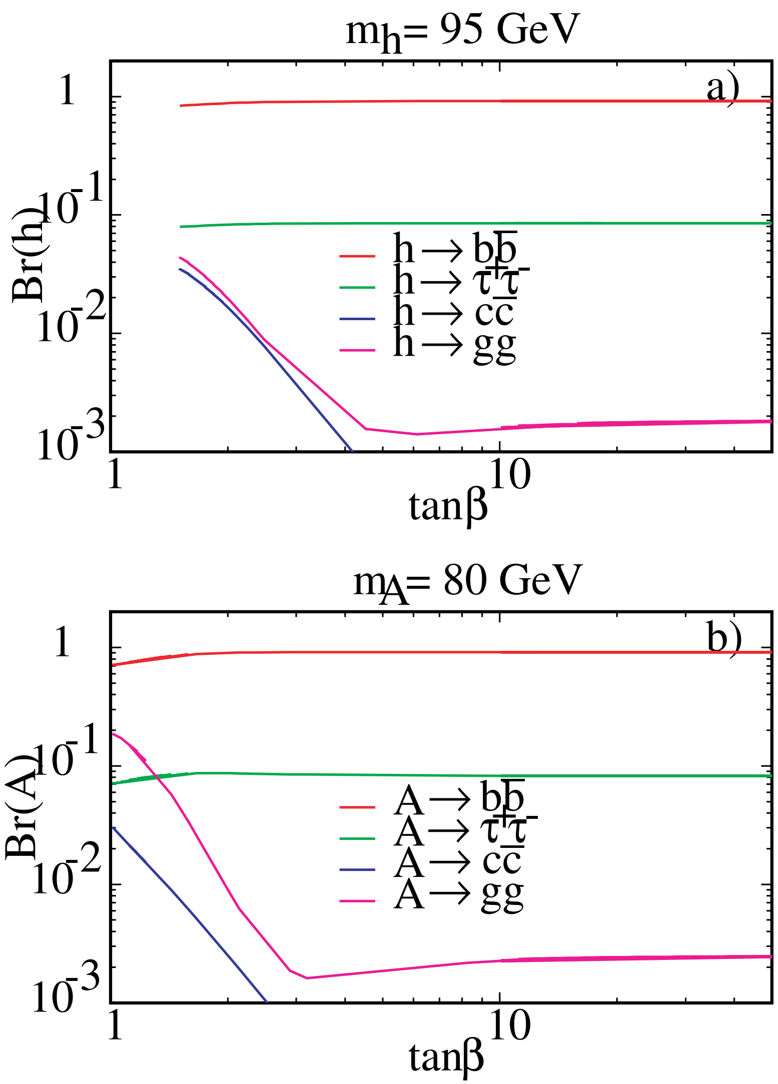
ratio of the two Higgs vacuum expectation values $\tan\beta$,
mass of A boson m_A,
gaugino mass parameter M_2,
universal scalar fermion mass m_0,
common scalar quark trilinear coupling A,
Higgs mixing parameter μ.

The results are interpreted within the two scenarios:

- "Maximal Mixing" such that m_h acquires its maximal value for any given value of m_A and $\tan\beta$ and gives most conservative limits.
- "Minimal Mixing" where there is no mixing in the scalar top sector ($\mathrm{X_t = A} - \mu\cot\beta = 0$).

free parameters $\Rightarrow$ $\mathrm{m_A}$ and $\tan\beta$

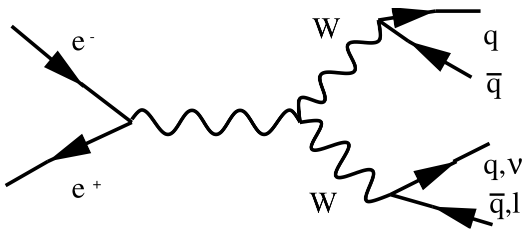
Neutral Higgs Bosons Decays

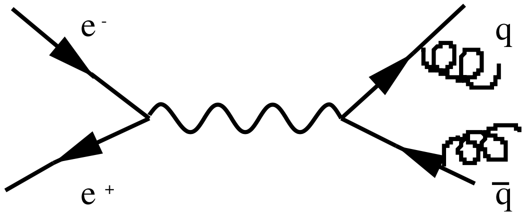


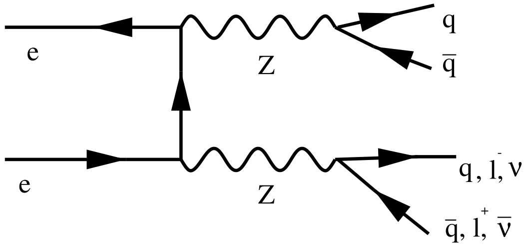
The Higgs decay into $b\bar{b}$ is dominant on all the $\tan\beta$ range

- **most of the SM analyses are used in the hZ channels**
- **dedicated analyses to search for $\mathrm{h}A \rightarrow b\bar{b}b\bar{b}$ and $\mathrm{h}A \rightarrow b\bar{b}\tau^+\tau^-$**

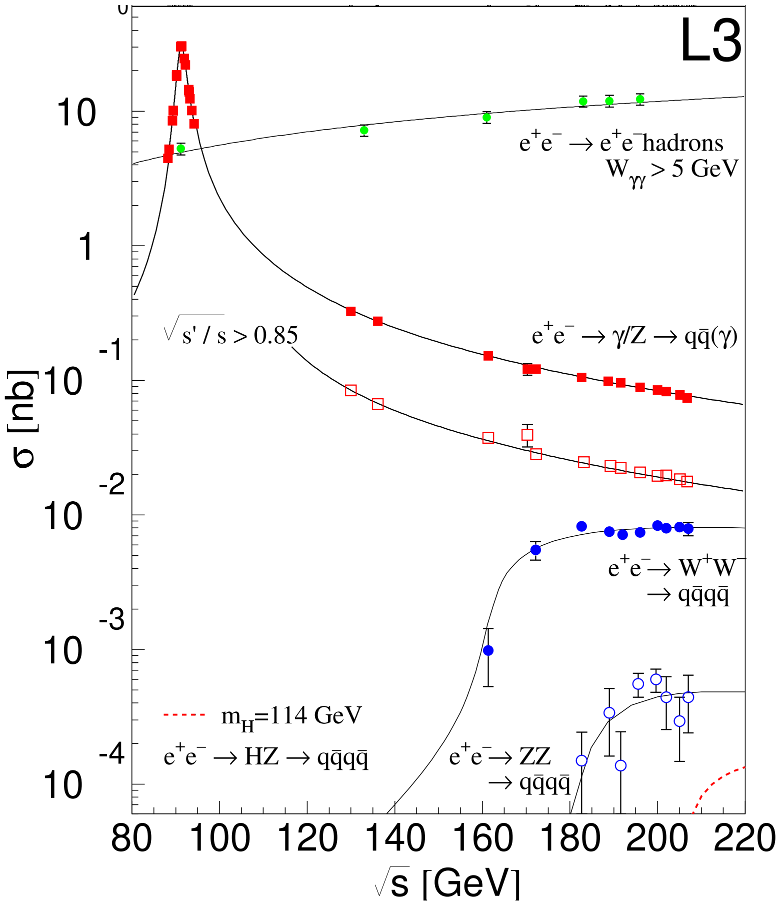
Backgrounds



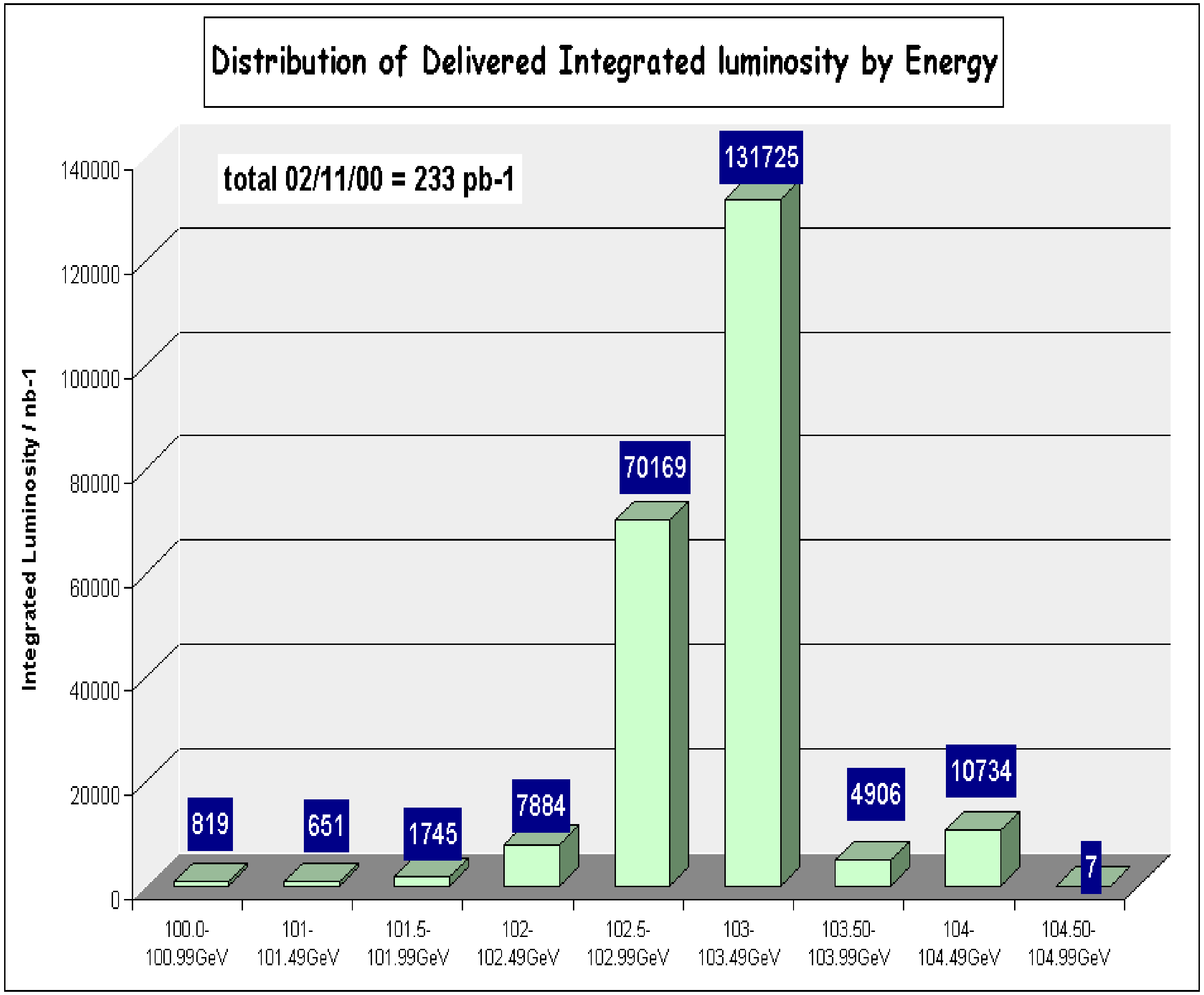




- W^+W^- and ZZ are pair production similar to hZ, hA
- b-tag very important to reject backgrounds
- backgrounds cross sections $\sim 10^5$ times the signal cross section

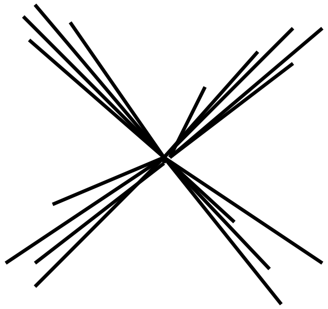


LEP: Last Year Data Taking



More than 230 pb^{-1} per experiment

Analysis Procedures: L3



4-jet Channel:

$hA \longrightarrow b\bar{b}b\bar{b}$,

$hZ \longrightarrow b\bar{b}q\bar{q}$

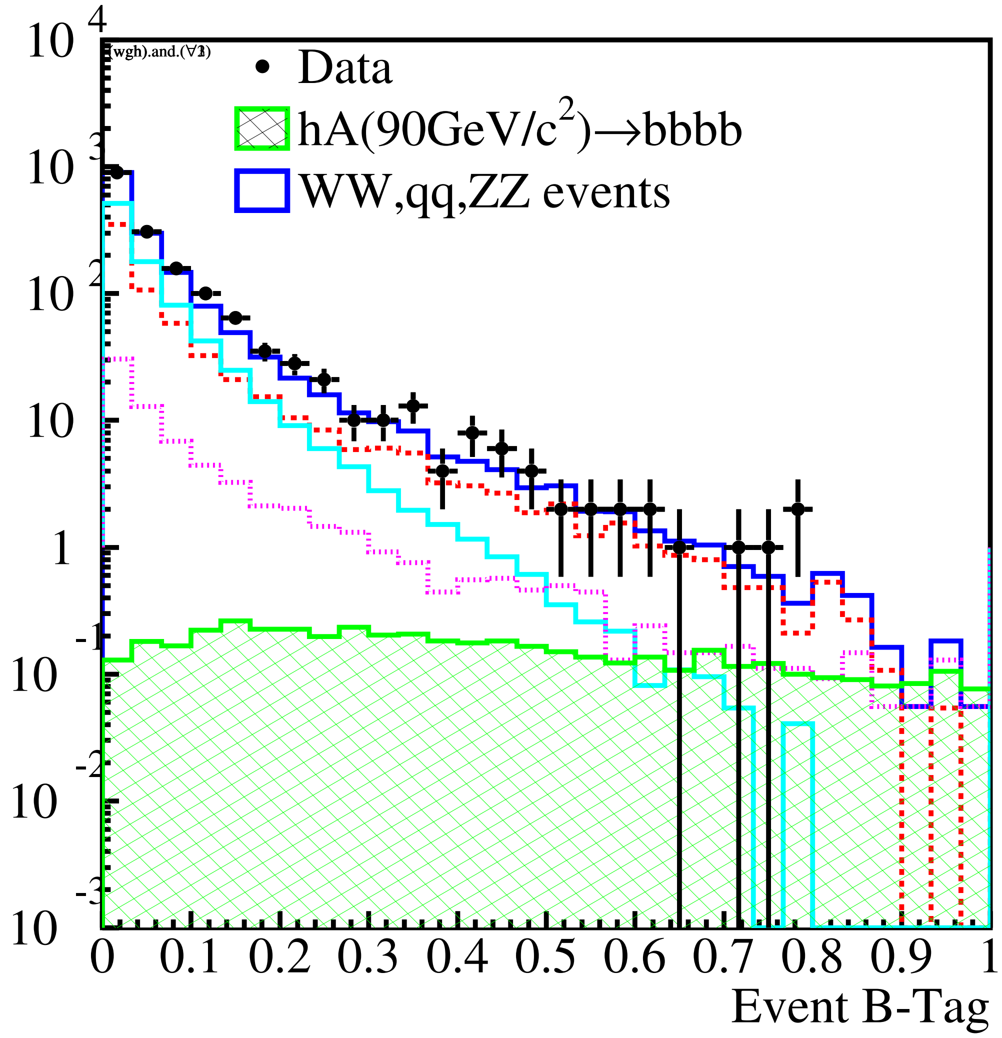
- Hadronic Preselection common to hZ and hA to reduce the backgrounds while keeping the signal efficiencies high ($\sim 90\%$)
- good agreement DATA/BKG:

$\mathcal{L}_{int}$(pb^{-1})	$\sqrt{s}$(GeV)	DATA	BKG	$q\bar{q}$	W$^+$W$^-$	ZZ
10.2	200.0-205.5	162	133.1	54.2	73.1	5.7
83.0	205.5-206.5	1130	1073.0	433.9	591.8	47.1
123.6	206.6-209.0	1679	1597.0	642.7	883.5	71.0

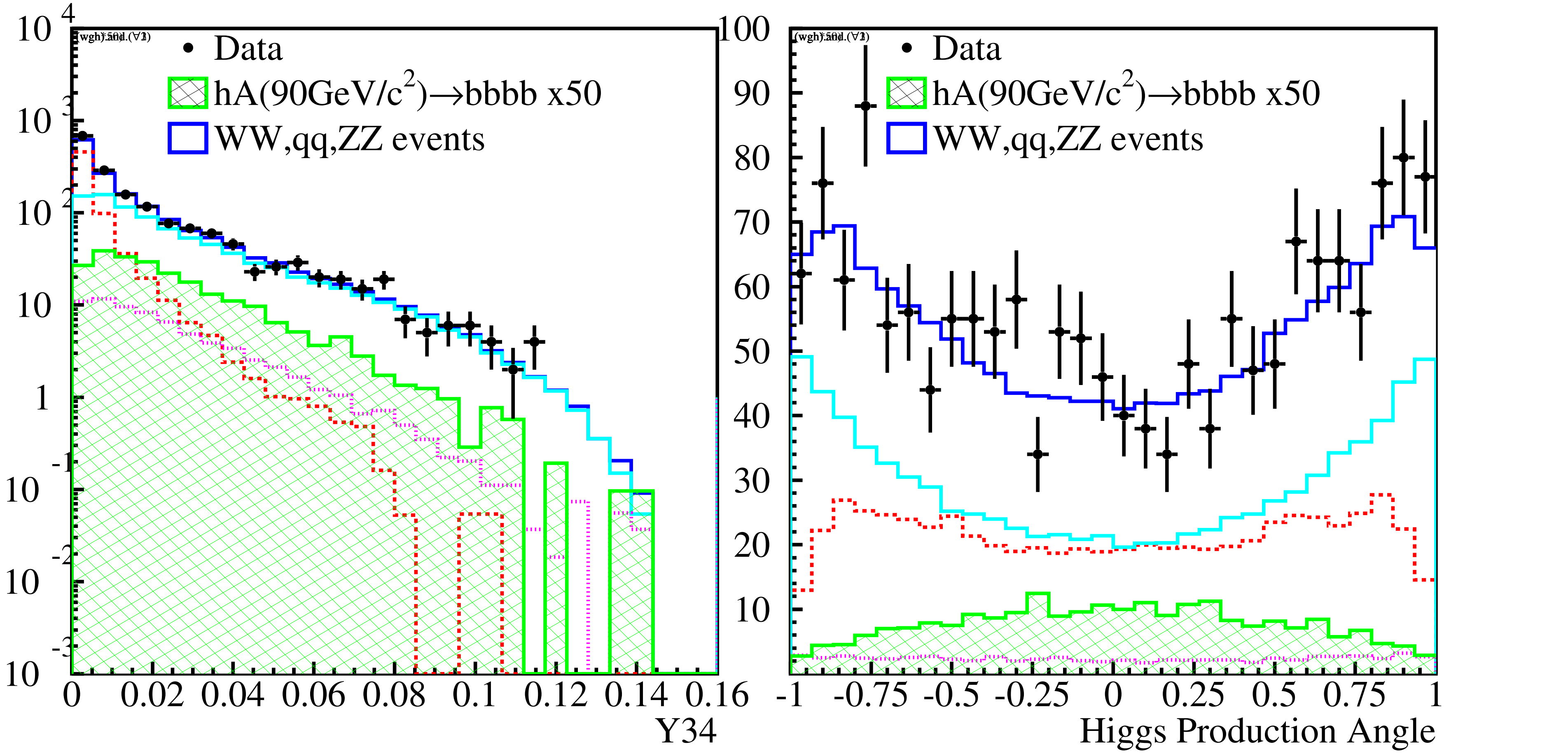
- The events are reconstructed into 4-jet topology
- The most discriminating variables combined in a NEURAL NETWORK

NN Inputs: Event B-TAG

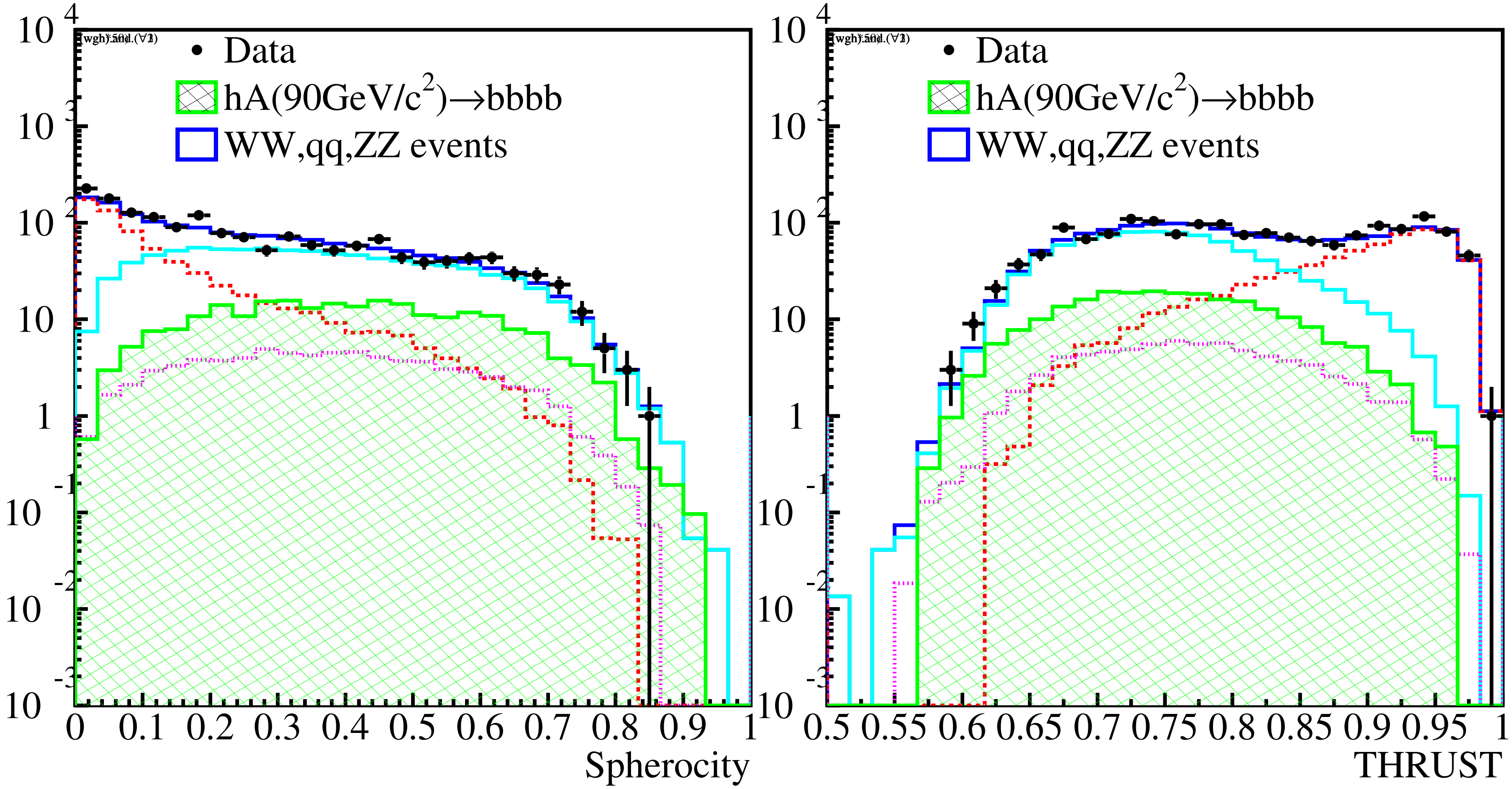
The Event B-Tag is a probability combination of the single jet tagging



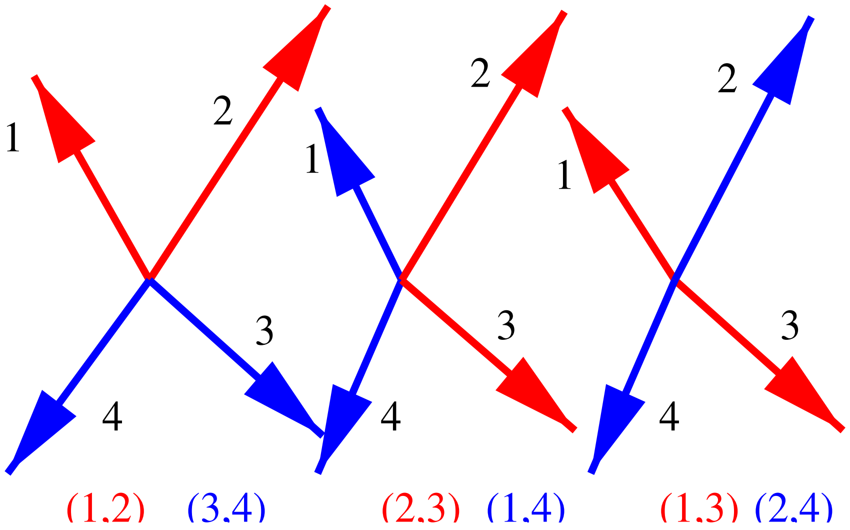
NN Inputs: Topology Variables

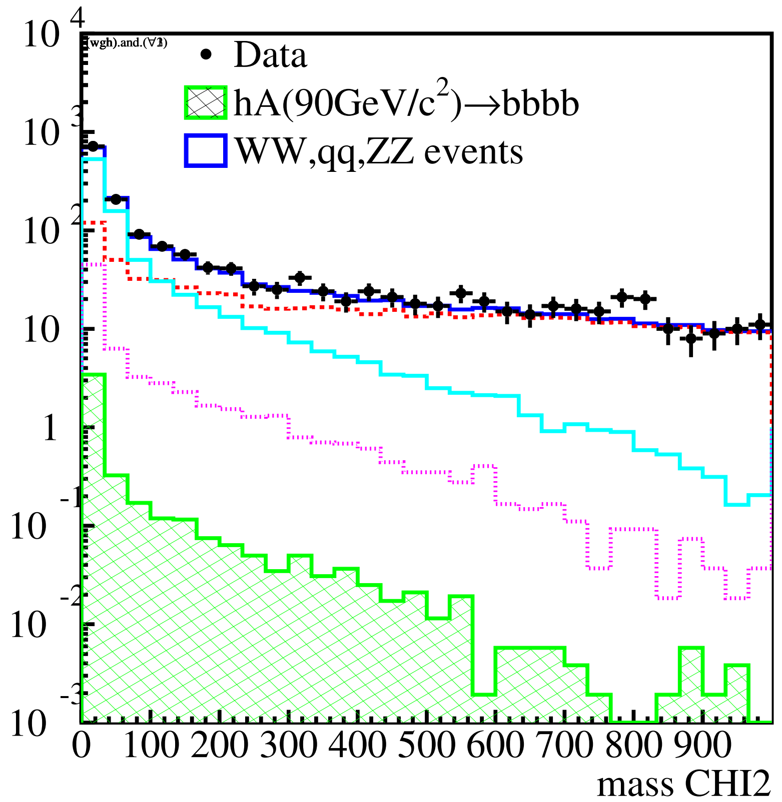


NN Inputs: Topology Variables



NN Inputs: Mass Information





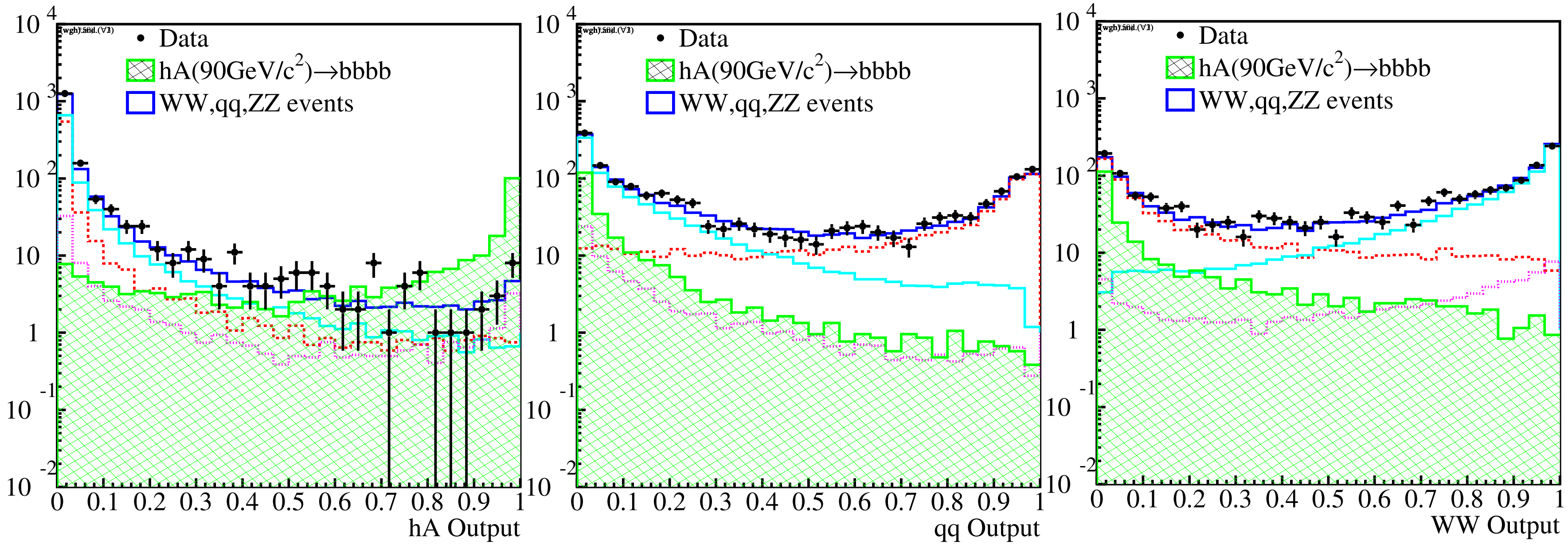
4 jets ⇒ 6 jet pairs (dijet) ⇒ 3 combinations of the dijet pairs (pairing)

The pairing which satisfies the best tested mass hypothesis is chosen. The mass χ^2 quantifies the consistency with the mass hypothesis.

Neural Network Outputs

One variable for each event class

$\mathbf{OUT_{Signal}}$ $\mathbf{OUT_{q\bar{q}}}$ $\mathbf{OUT_{WW}}$

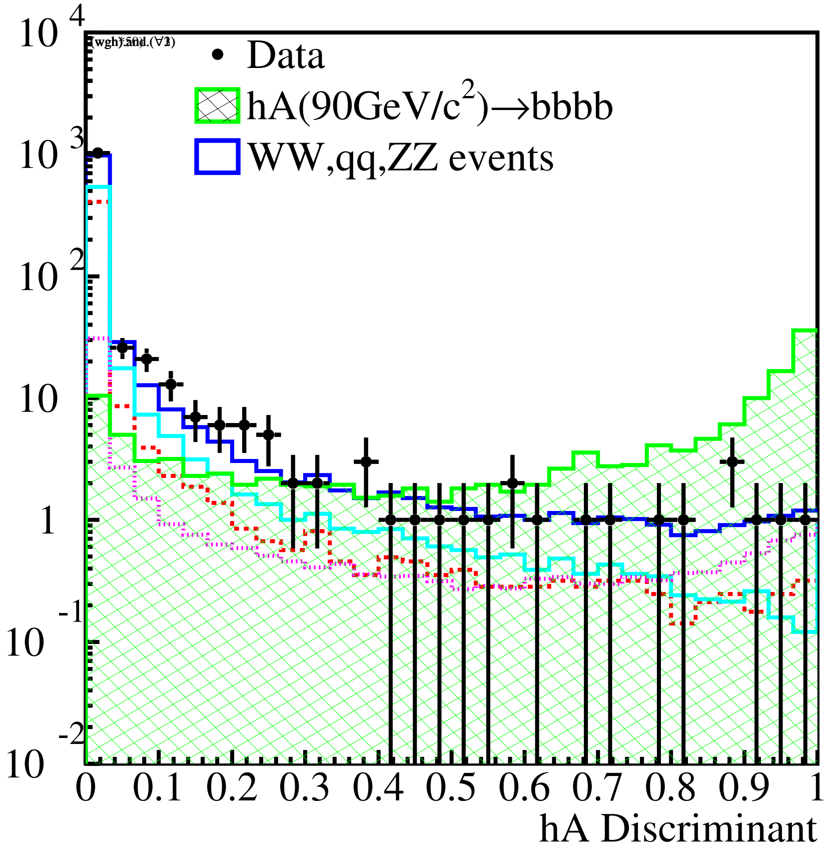


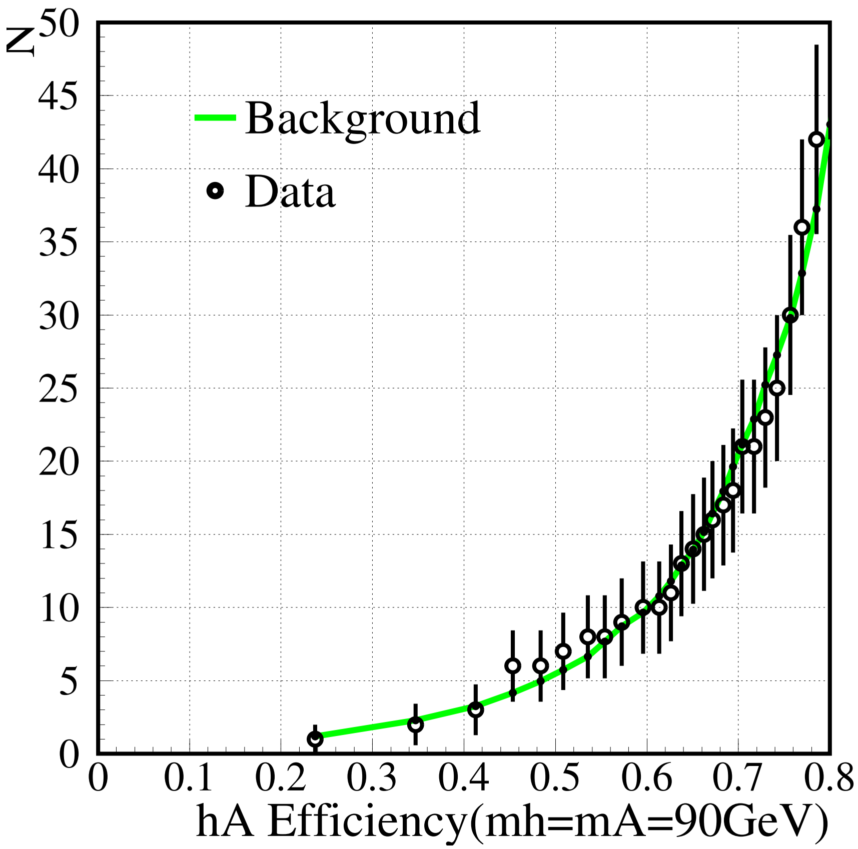
The Discriminant is:

$$\mathbf{OUT_{Signal} \cdot (1 - OUT_{WW}) \cdot (1 - OUT_{q\bar{q}})}$$

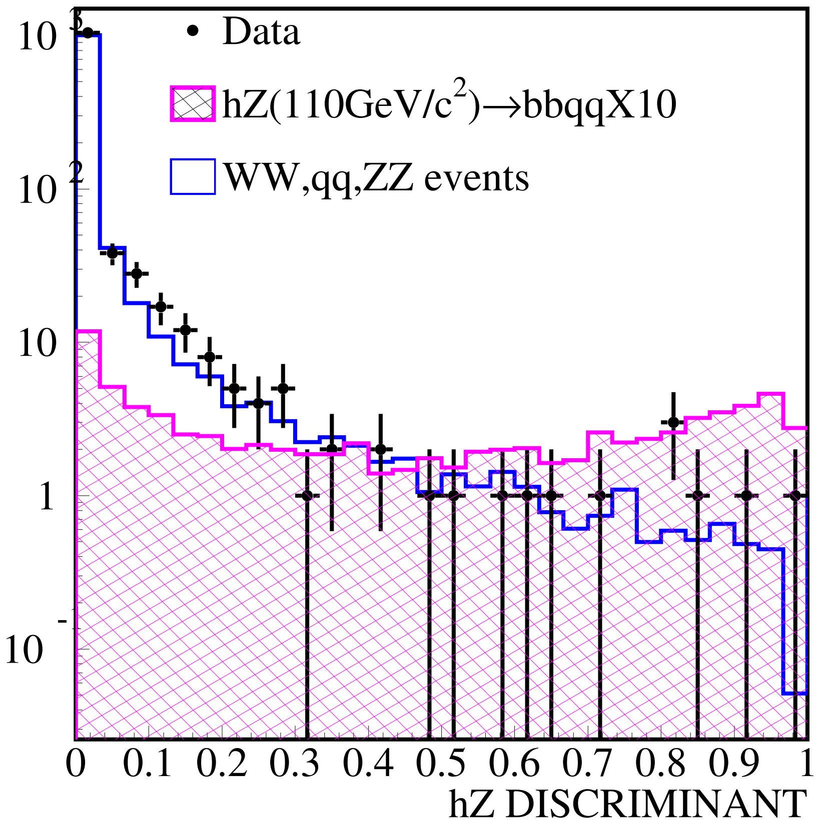
hA Discriminant

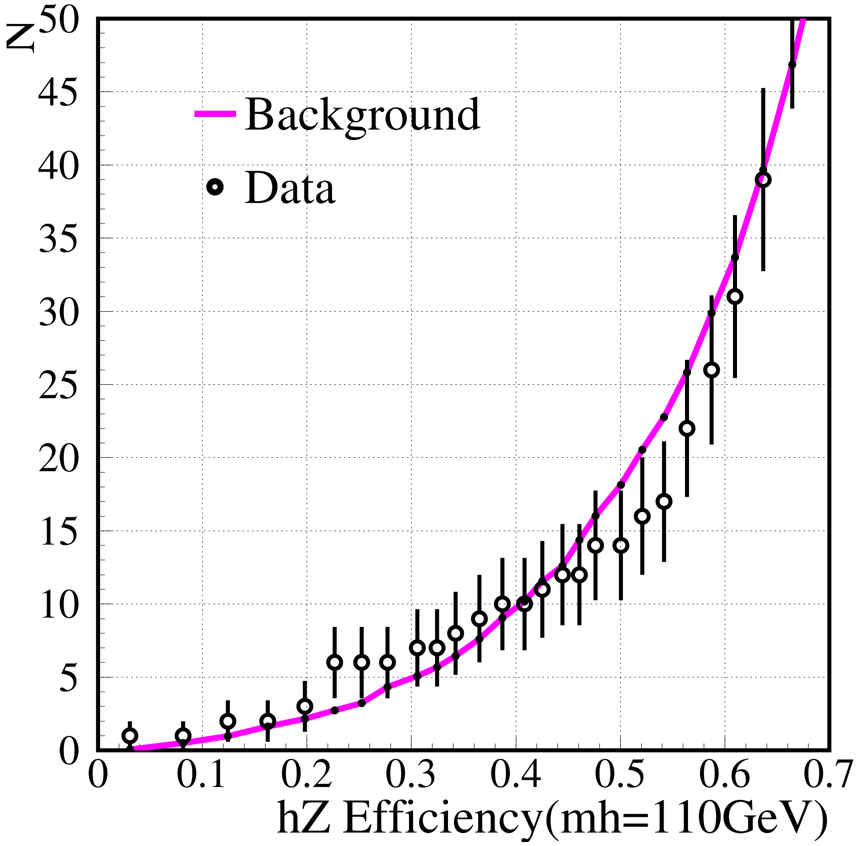
The NN outputs are combined in this final discriminant





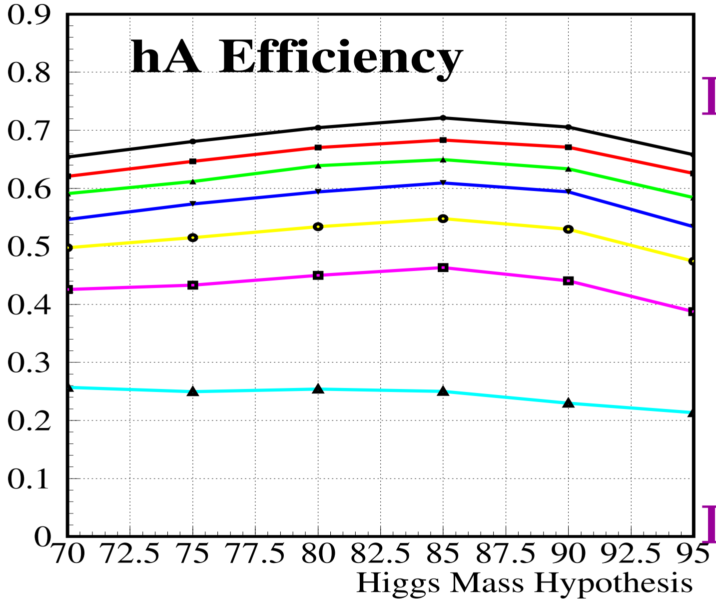
hZ Discriminant





NN Outputs

The shape of the Discriminant is almost independent of the Higgs mass hypothesis

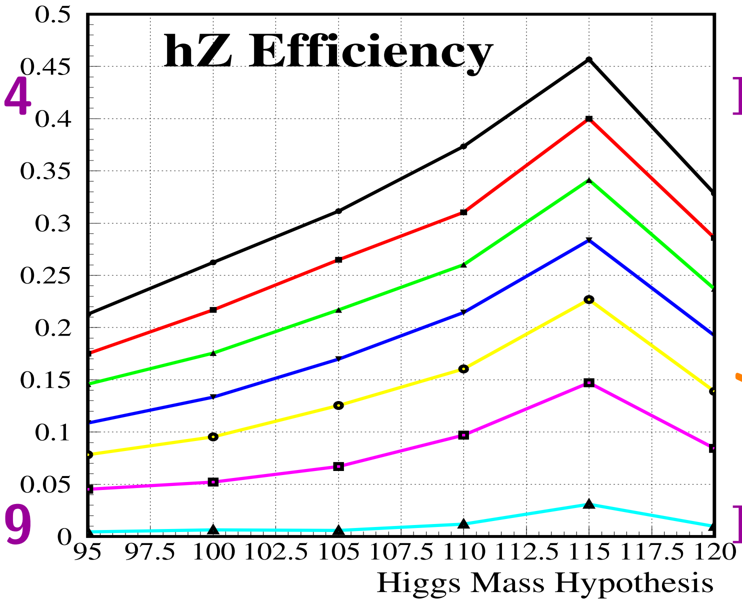


Cut:

D >0.4

⇓

D >0.9



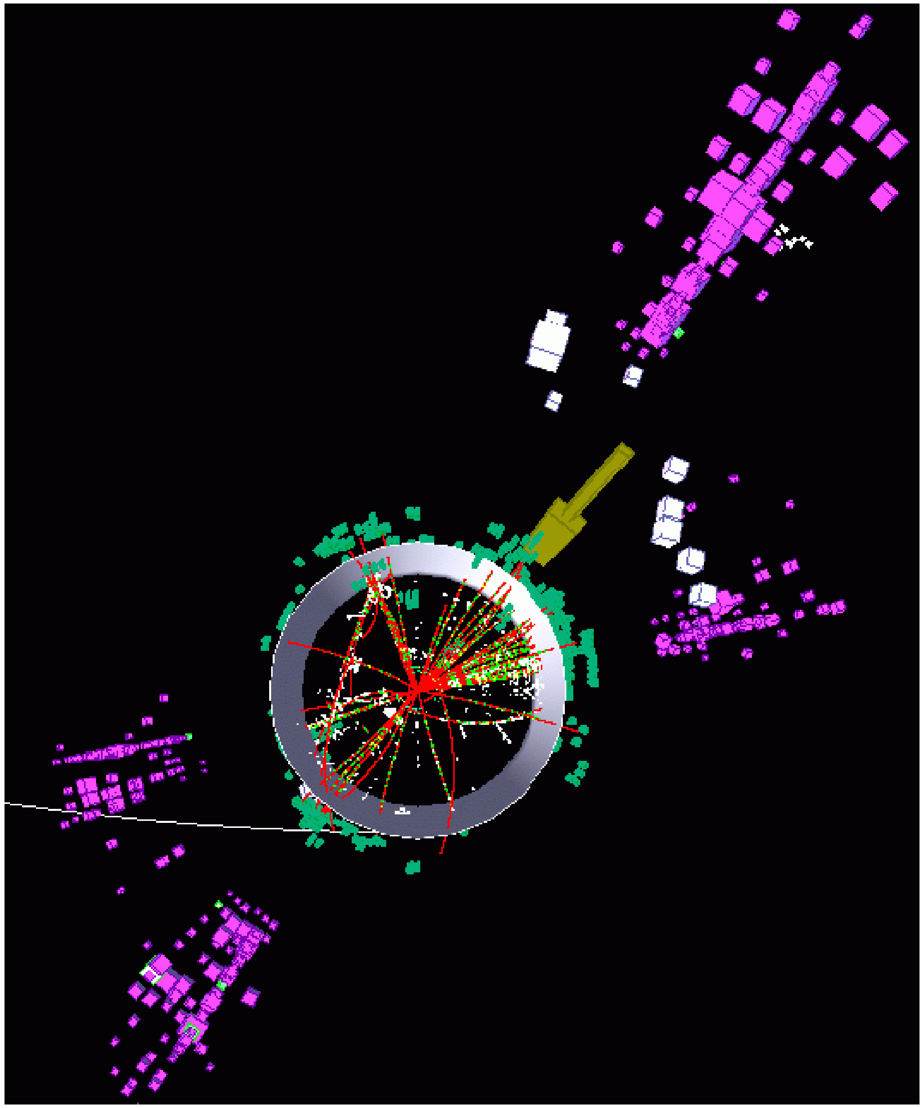
Cut:

D >0.4

⇓

D >0.9

L3 Candidate: $hA \longrightarrow b\bar{b}b\bar{b}$

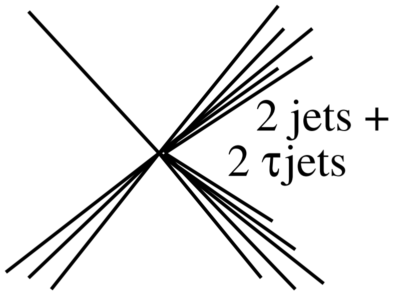


high B-tag= 0.6

Discriminant= 0.98

$m_h + m_A$= 178.8 GeV

Analysis Procedures: L3



$b\bar{b}\tau^+\tau^-$ Channel:

$$hA \rightarrow b\bar{b}\tau^+\tau^-,$$
$$hZ \rightarrow b\bar{b}\tau^+\tau^-$$

- **Main background from W^+W^- decays containing taus**
- **4-jet topology with two of them being narrow and of low multiplicity**

After the selection:

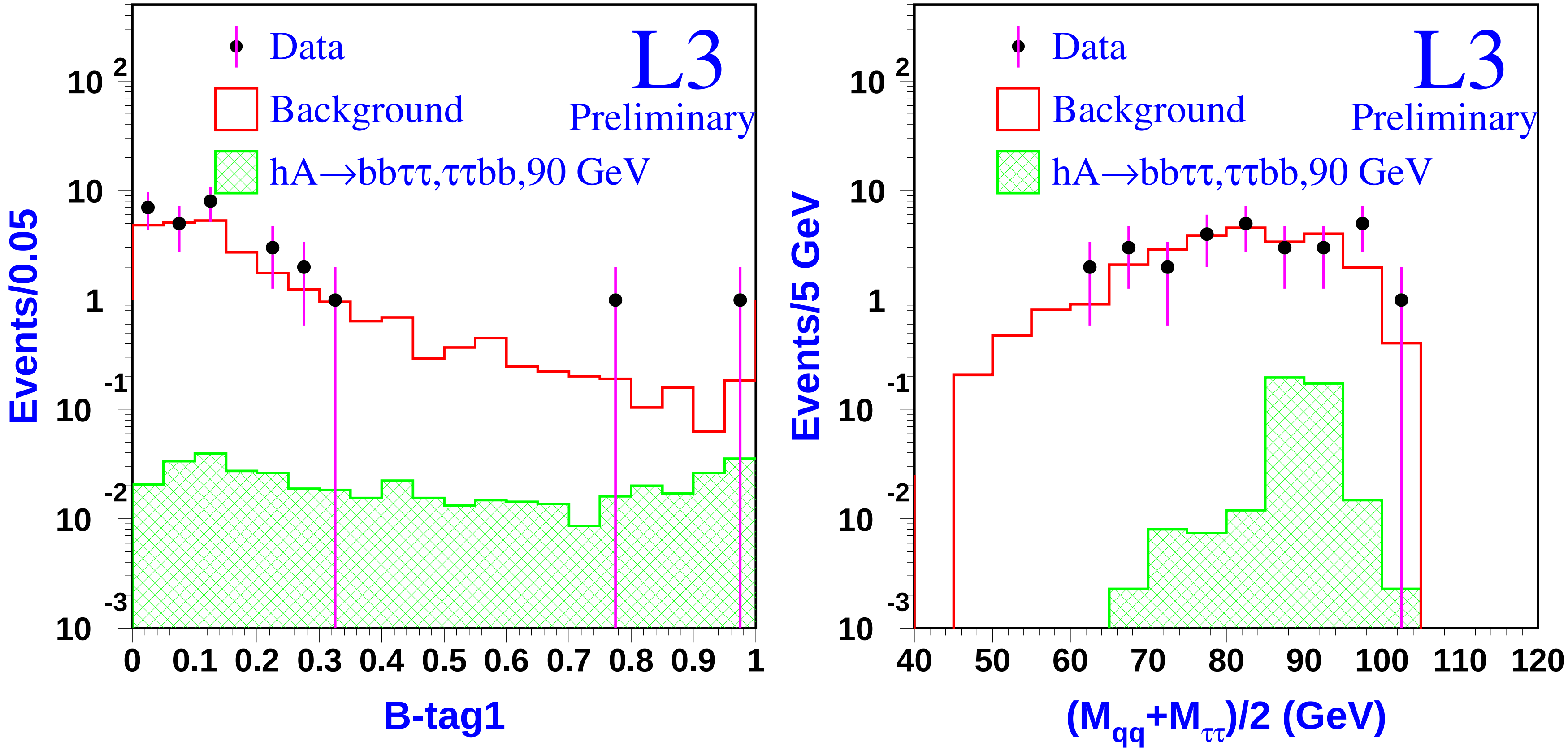
DATA 28

ALL BKGS 25.7

$$\varepsilon(m_h = m_A = 90\mathrm{GeV}) = 34.7\%$$

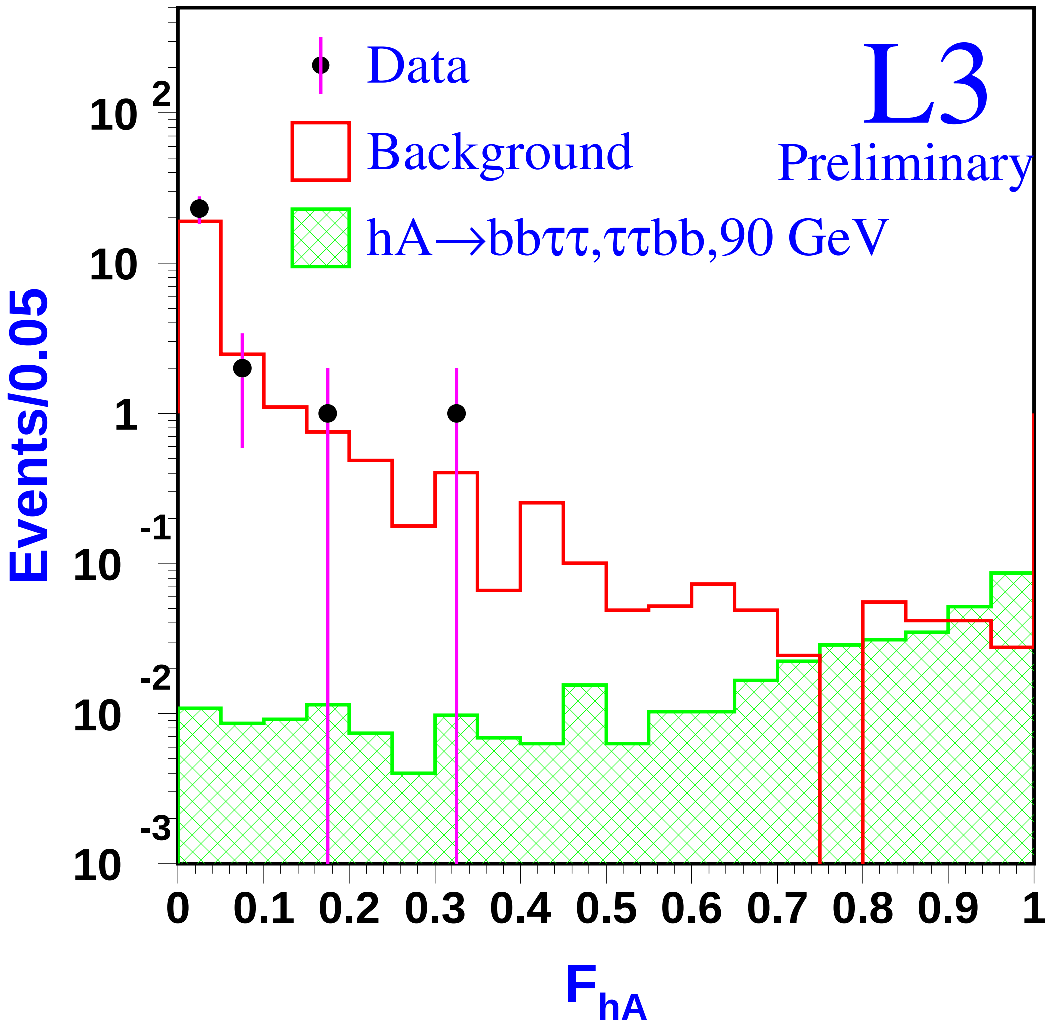
- **The discriminating variable is based on the Likelihood approach**

Analysis Procedure: $\mathrm{b\bar{b}}\tau^+\tau^-$ Channel

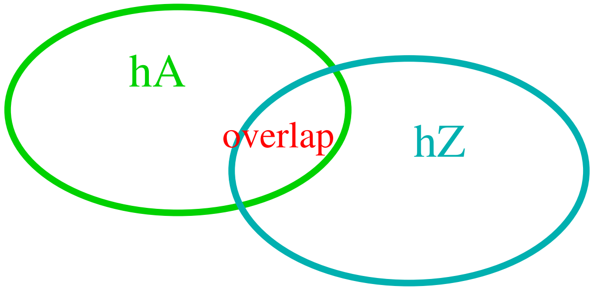


Analysis Procedure: $b\bar{b}\tau^+\tau^-$ Channel

The **B-Tag** of the two hadronic jets and the **reconstructed mass** of the hadronic and $\tau^+\tau^-$ systems are combined into a Likelihood



Analysis Procedures: L3



- Two independent analyses for hA and hZ
- To calculate the confidence Level it is necessary to give only one assignment to each event (data, backgrounds and signal)

IF
hA-Discriminant $>$ hZ-Discriminant

THEN $\Rightarrow$ hA assignment

ELSE $\Rightarrow$ hZ assignment

The signal distributions are extrapolated to cover all the $(\mathrm{m_h}, \tan\beta)$ and $(\mathrm{m_A}, \tan\beta)$ planes

Confidence Level

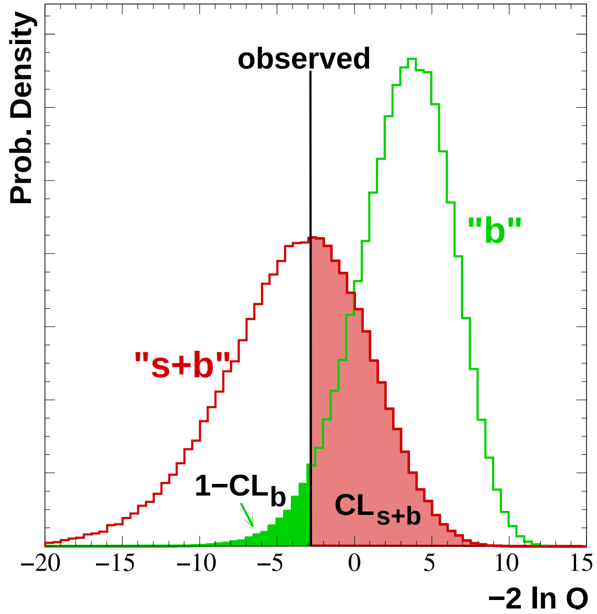
To establish a method for the exclusion or discovery

By simulated experiments a `test-statistics` X is constructed on the two hypotheses:

- **SIGNAL + BACKGROUND**
- **BACKGROUND**

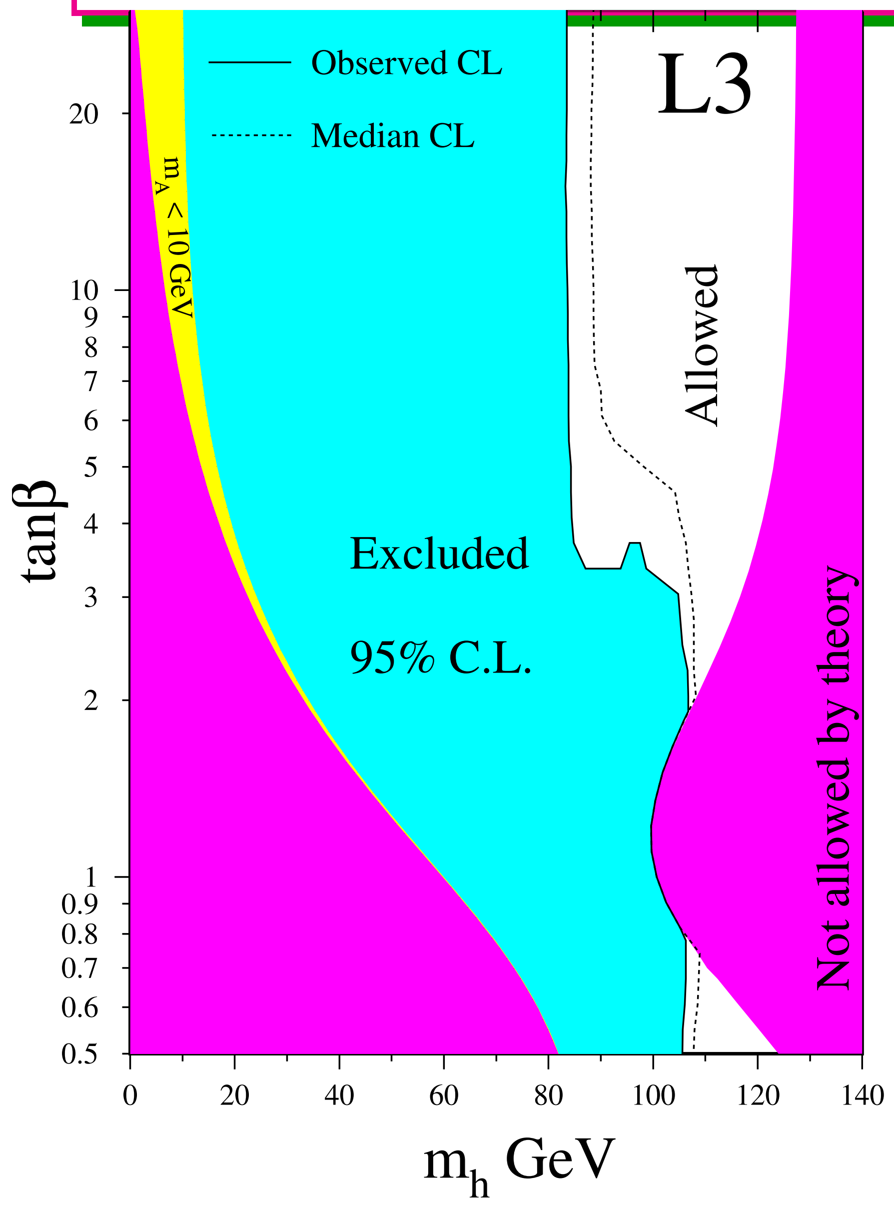
The Confidence Level is defined:

- $CL_{s+b} = P_{s+b}(X \leq X_{obs})$
- $CL_b = P_b(X \leq X_{obs})$



$$\Rightarrow CL_s \equiv CL_{s+b}/CL_b$$

Preliminary L3 Results



Maximal Mixing Scenario

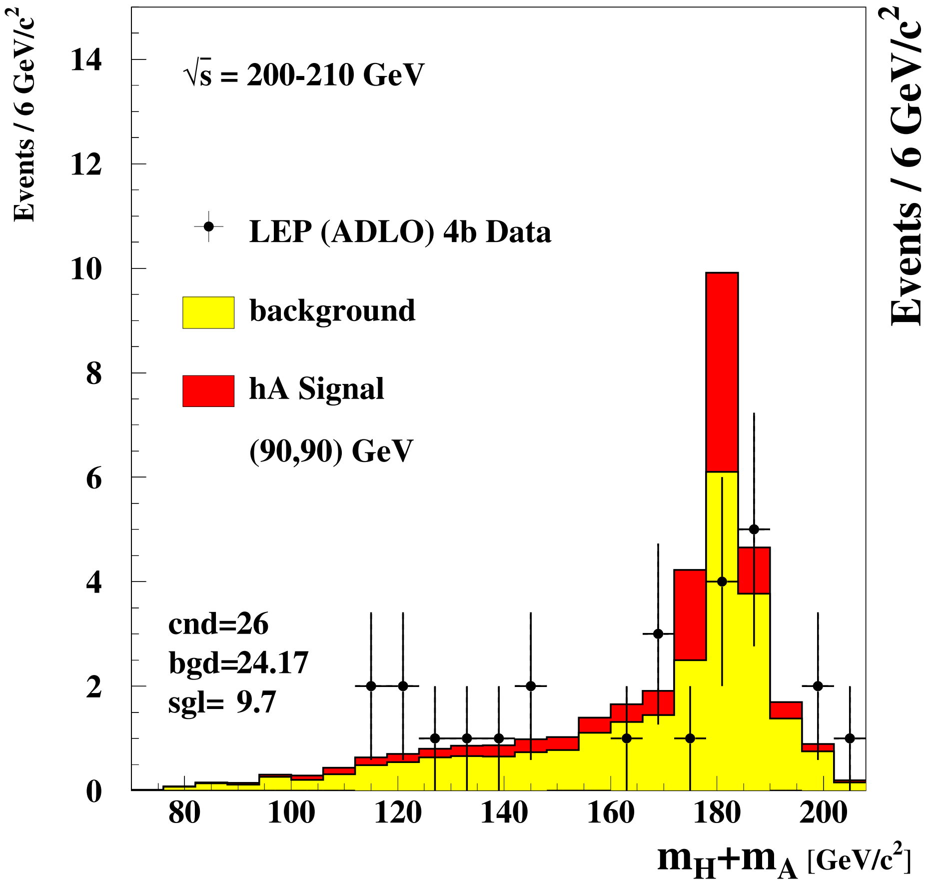
$m_h > 83.7$ GeV
(exp. $m_h > 88.1$ GeV)

$m_A > 83.9$ GeV
(exp. $m_A > 88.3$ GeV)

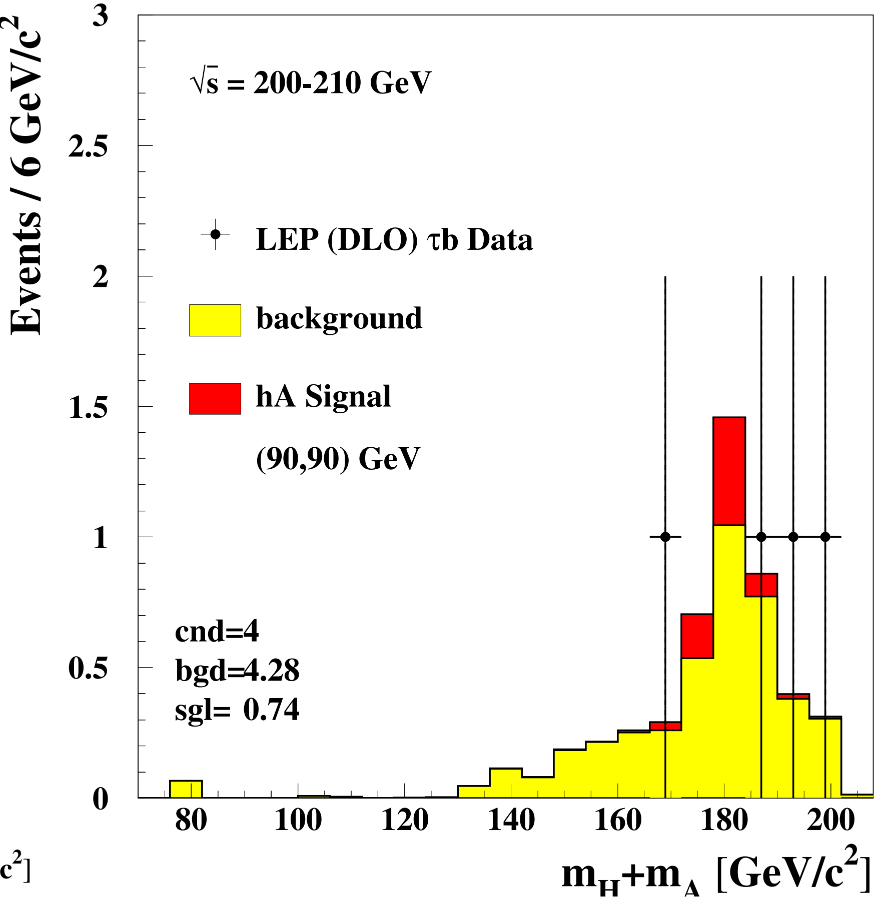
$0.77 > \tan\beta > 1.9$
($0.72 > \tan\beta > 1.95$)

Combined Reconstructed Mass

4-jet Channel

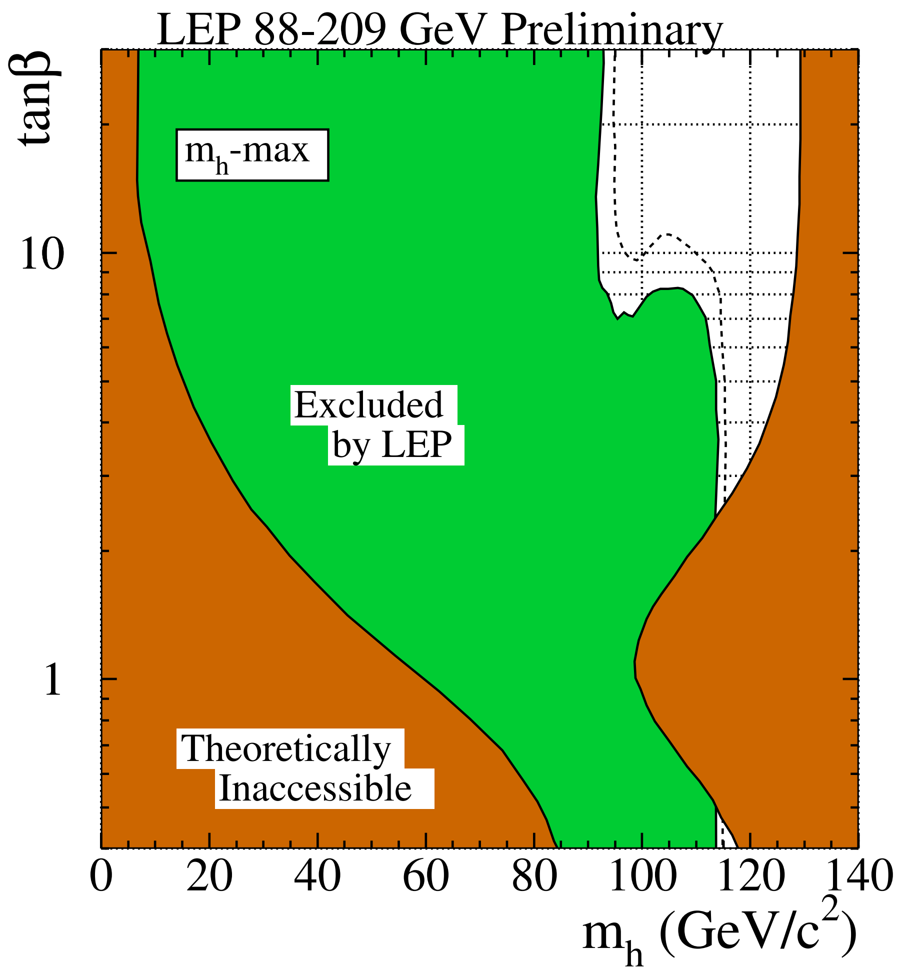


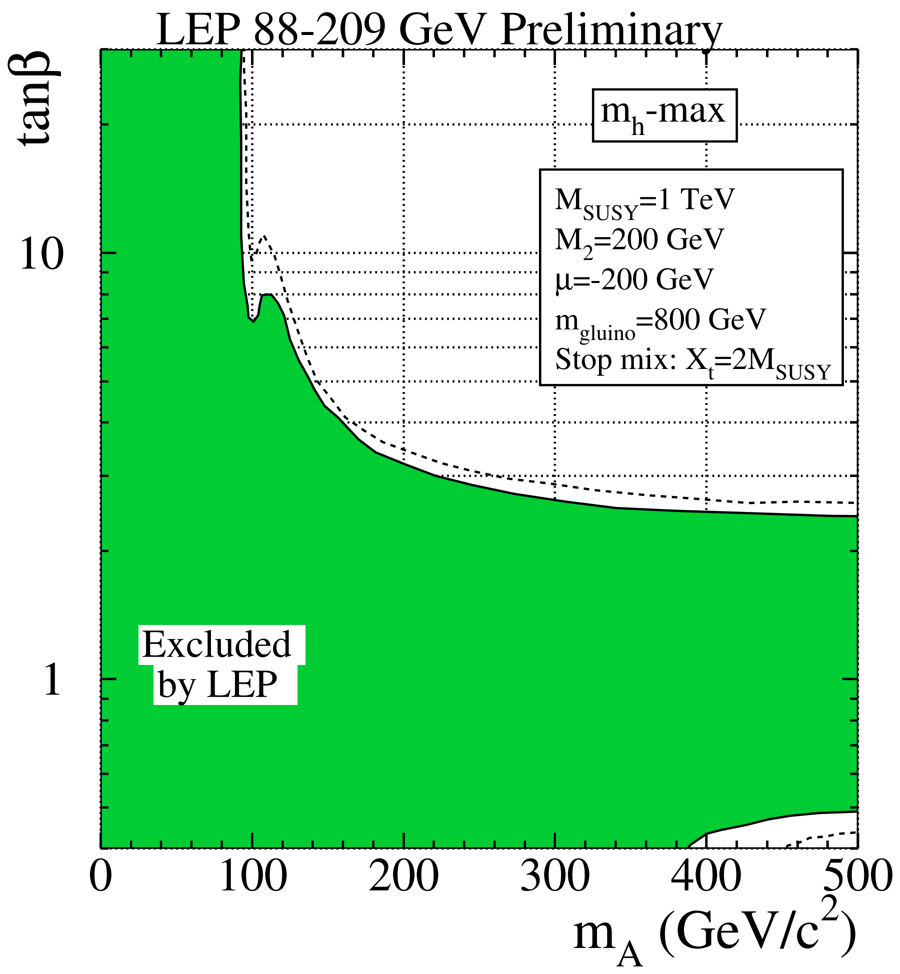
$b\bar{b}\tau^+\tau^-$ Channel



Preliminary LEP Combined Results

Maximal Mixing Scenario





Preliminary LEP Combined Results

	ALEPH	DELPHI	L3	OPAL
m_h obs./exp. (GeV)	89.0/90.0	85.2/87.8	83.7/88.1	83.4/88.7
m_A obs./exp. (GeV)	89.1/90.3	86.5/89.2	83.9/88.3	84.2/89.7

$$m_h > 89.9\ GeV\,(93.8\ GeV)$$
$$m_A > 90.5\ GeV\,(94.1\ GeV)$$

$\tan\beta$ excluded from 0.52 to 2.25 (from 0.48 to 2.48) [a]

[a] Results updated October 10.
Last available combined results: ALEPH 2000-074 CONF 2000-051; DELPHI 200-148 CONF 447; L3 Note 2600; OPAL Technical Note TN661.

Conclusions

- Excellent LEP performance during the last year:
  - $\sqrt{s}$ up to 210 GeV
  - more than 200pb^{-1} per experiment
- A general good agreement is found between the data and the Standard Model backgrounds
- $\Rightarrow$ NO EVIDENCE of the production of the MSSM Neutral Higgs bosons. The results are interpreted within two MSSM scenarios. Preliminary lower mass limits from LEP Combined data at 95% C.L. are set:

$$\boxed{m_h > 89.9 \text{ GeV} \quad m_h > 90.5 \text{ GeV}}$$

with $m_h > 93.8$ GeV and $m_h > 94.1$ GeV expected limits