L3 Higgs Searches at $\sqrt{s} = 189$ GeV (SM update for $192 - 196$ GeV)

L3 Higgs Working Group
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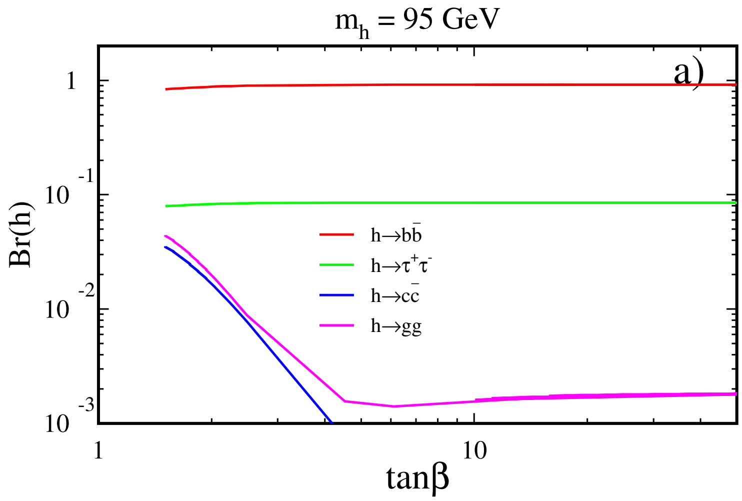
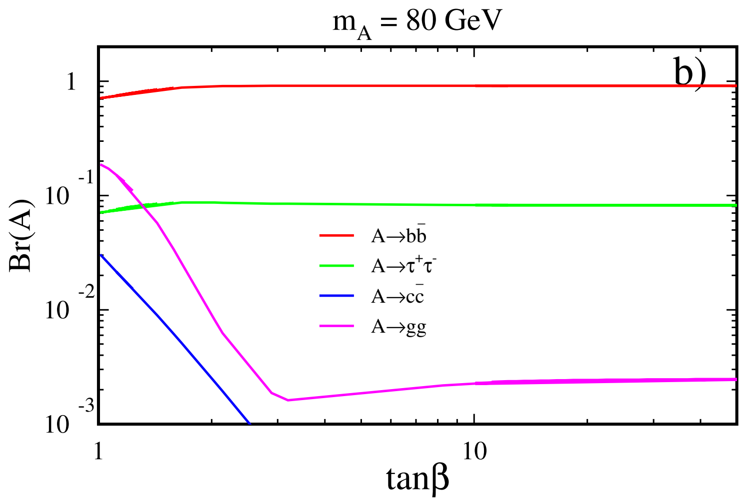
- Importance of B-Tag
- Standard Model Higgs
- Minimal Supersymmetric Standard Model Higgs
- Charged Higgs
- Conclusions





a) Important branching fractions of the h as a function of $\tan\beta$ for a fixed value of Higgs mass, $m_{\mathrm{h}} = 95\ \mathrm{GeV}$. $\mathrm{h} \to \mathrm{b}\bar{\mathrm{b}}$ is always large![1]

b) Same as (a) but for A branchings. $\mathrm{A} \to \mathrm{b}\bar{\mathrm{b}}$ is always large!

[1] With usual caveats about pathological MSSM parameter configurations.

B-Tag

Backgrounds!

SM processes	cross section (pb)	
	189 GeV	196 GeV
$e^+e^- \to e^+e^- q\bar{q}$ ($M_{q\bar{q}} > 15$ GeV)	4×10^3	4.5×10^3
$e^+e^- \to q\bar{q}$	98.3	89.7
$e^+e^- \to W^+W^-$ (except $q\bar{q}'e\nu$)	14.1	14.7
$e^+e^- \to Ze^+e^-$	3.4	3.5
$e^+e^- \to q\bar{q}'e\nu$	2.9	3.1
$e^+e^- \to ZZ$	0.97	1.2
$e^+e^- \to Z^* \to hZ$ (SM $m_h = 95$ GeV)	0.17	0.32

- W^+W^-, ZZ are bad because they are pair production "similar" to hZ, hA, H^+H^-.
- ZZ is particularly nasty since $\sim 44\%$ contain at least 1 $b\bar{b}$ pair.

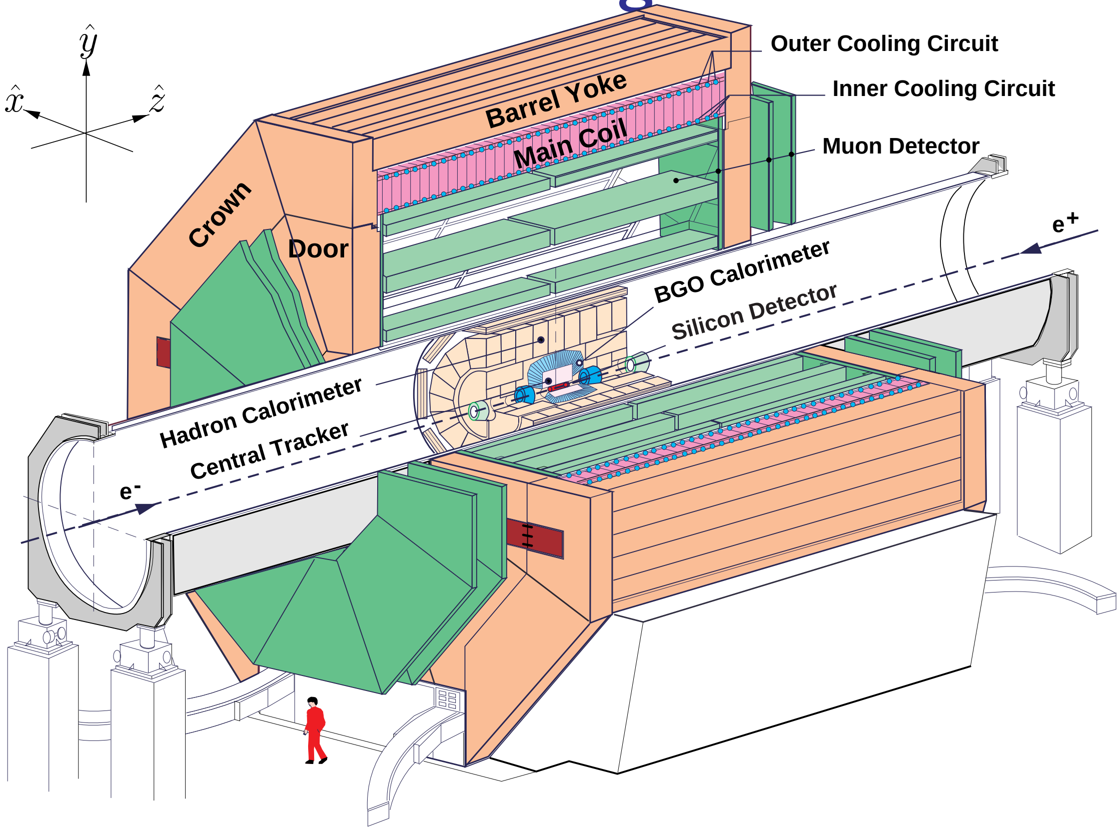
B-Tag

General Idea of B-Tagging

- Average b hadron lifetime is 1.56 ps.
- Most lighter flavored hadrons either have no discernible lifetime or are very long lived (K^0_S,K^0_L,Λ^0).
- Charm and tau lifetimes are typically less than half as long as b lifetime.
- At LEP $\sqrt{s}$, the hadrons are highly boosted $\Rightarrow$ b decay lengths $\mathcal{O}(3\ \mathrm{mm})$.

Use this decay length to "tag" production of b quarks.

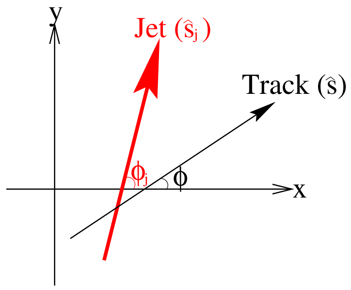
B-Tag



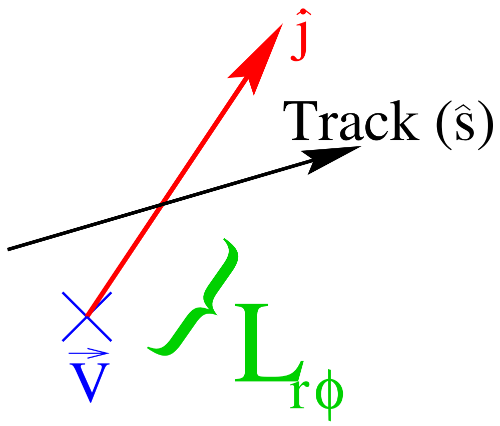
- Muon chambers: 3 layers of $r - \phi$ and 2 layers of z achieve a $\sim 2\%$ momentum resolution for 45 GeV $\mu^+\mu^-$.
- Calorimeters: HCAL covers 99% of solid angle. ECAL gives excellent photon, electron resolution–$1\% \oplus 2\%/\sqrt{E}$. ECAL+HCAL give about 10% measurement of jet energy.
- Central Tracking: TEC+SMD can give position resolution at IP of 35 $\mu\mathrm{m}$, angular resolution of 3 mrad, p_t resolution of $0.011\ \mathrm{GeV}^{-1}$.

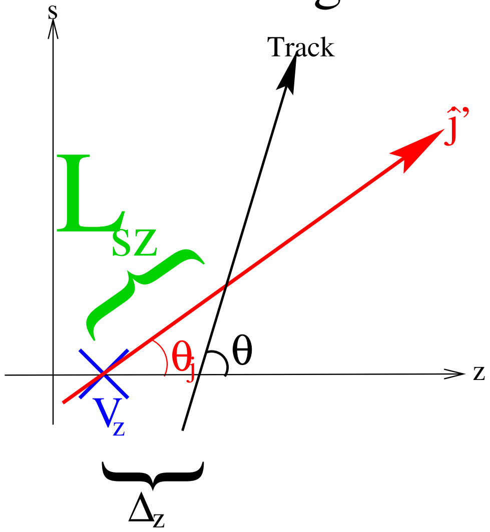
B-Tag

Decay Length Method



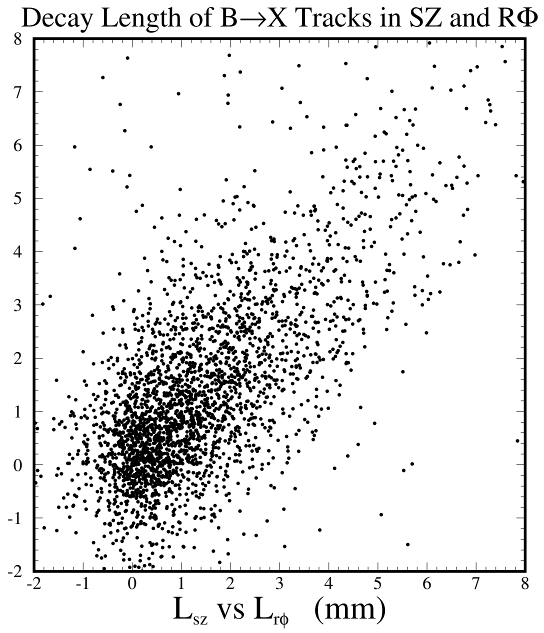
Choose ŝ along track

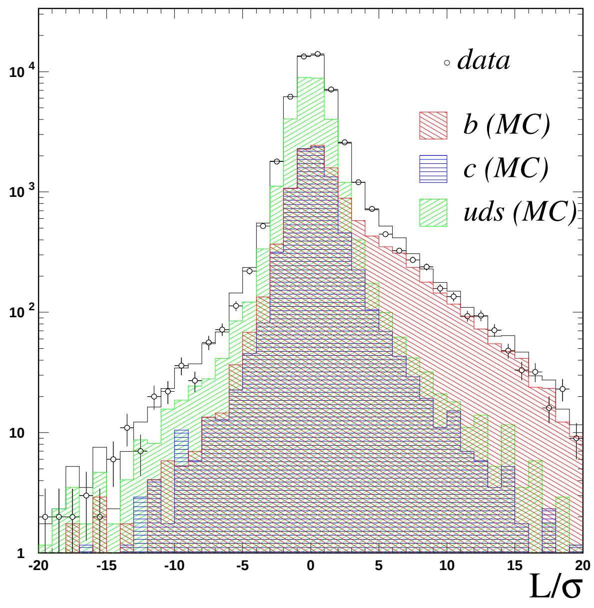




- Define w.r.t. primary event vertex: $\mathrm{RMS}_V = (51, 10, 118)\ \mu\mathrm{m}$ in ucsd events, $(81, 11, 154)\ \mu\mathrm{m}$ in b events
- 2 ∼independent and complimentary measurements of decay length.
- Can make χ^2 and weighted average of 2 decay lengths.

B-Tag





$$L = \frac{L_{r\phi}/\sigma^2_{L_{r\phi}} + L_{sz}/\sigma^2_{L_{sz}} - \frac{(L_{r\phi}+L_{sz})c_{\phi z}}{\sigma^2_{L_{r\phi}}\sigma^2_{L_{sz}}}}{1/\sigma^2_{L_{r\phi}} + 1/\sigma^2_{L_{sz}} - \frac{2c_{\phi z}}{\sigma^2_{L_{r\phi}}\sigma^2_{L_{sz}}}}$$

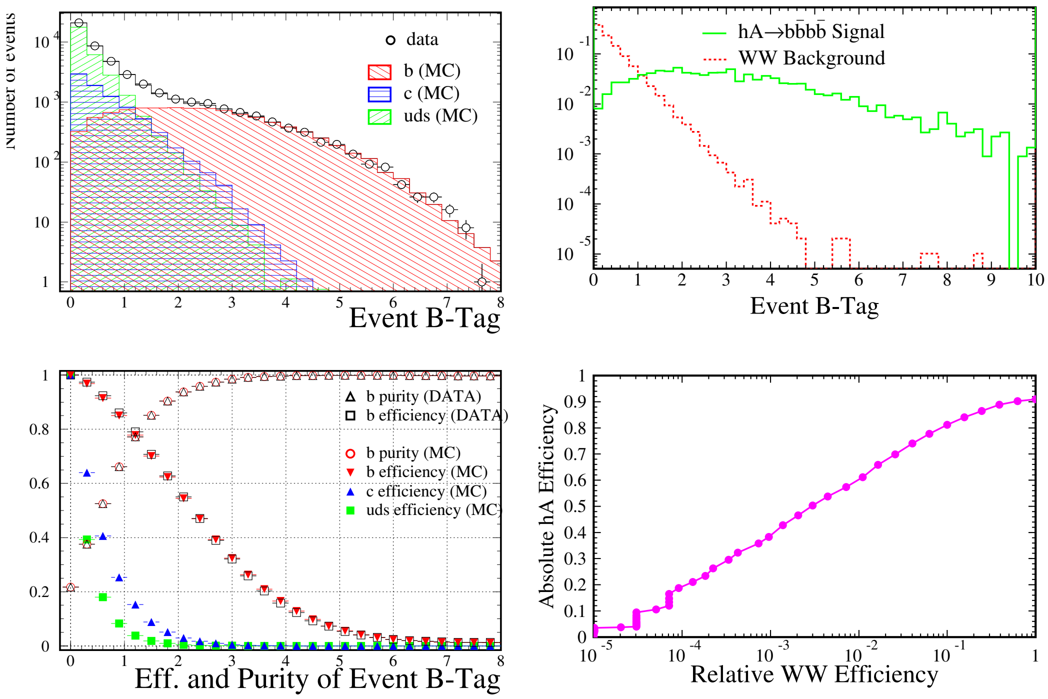
If $L_{r\phi}$, L_{sz} inconsistent (χ^2 test) $\Rightarrow$ assume $L_{r\phi}$ is correct, L_{sz} wrong due to pattern recognition problems.

B-Tag

Improve B-Tag with Neural Network

- Train NN to recognize jets with b hadrons.
- Most important input is decay length info.
- Secondary vertex information
  - Eff. to find secondary vertex in b jet is $\sim 50\%$.
  - Number of secondary, tertiary vertexes.
  - Decay length and error of secondary vertex.
  - Vertex mass.
- Inclusive lepton information
  - $\sim 6\%$ of b jets contain identified inclusive electrons and $\sim 12\%$ contain muons.
  - Information is completely orthogonal, esp. useful in high purity region.
  - Use p and p_t as inputs
- Jet shape variables
  - Energy dist. inside b jets slightly different from ucsd jets.
  - Boost of jet, and 4 most energetic clusters. Also boosted sphericity of jet.
- Also input polar angle of jet since decay length info degrades in forward region.

B-Tag

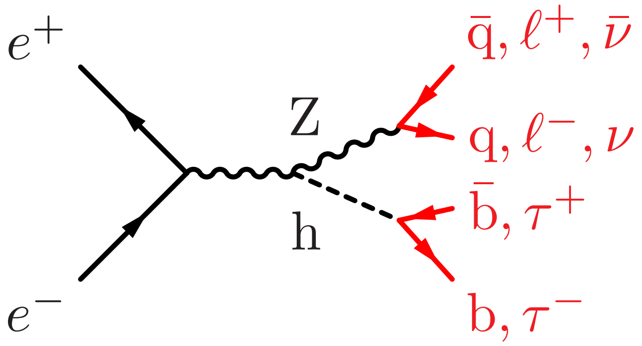


- 75% efficient at 80% purity on $Z \rightarrow b\bar{b}$ events in the barrel for $\sqrt{s} = 91$ GeV.

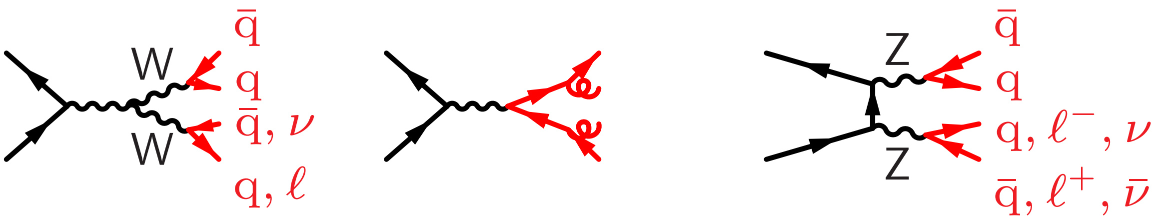
- Thousand-fold reduction in W^+W^- background while maintaining 40% hA efficiency at high energies.

Standard Model Higgs

Signal



Background



- Analyses Performed for
  - $\mathrm{hZ} \rightarrow \mathrm{b\bar{b}q\bar{q}}$
  - $\mathrm{hZ} \rightarrow \mathrm{b\bar{b}}\nu\bar{\nu}$
  - $\mathrm{hZ} \rightarrow \mathrm{b\bar{b}}\ell^+\ell^-$ $(\ell = \mathrm{e}, \mu, \tau)$
  - $\mathrm{hZ} \rightarrow \tau^+\tau^-\mathrm{q\bar{q}}$

- Includes charm, gluonic decays $\Rightarrow \sim 98\%$ Br.

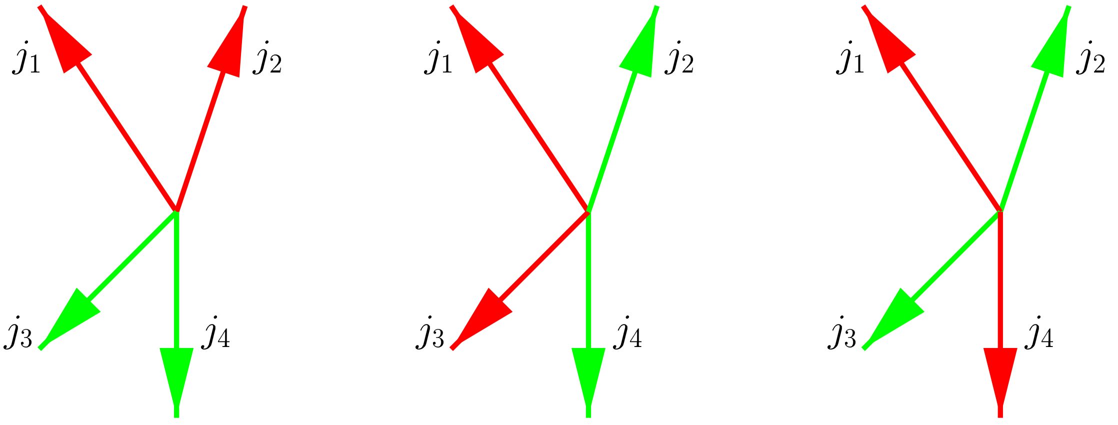
- Data collected: 176.4 pb^{-1} at $\sqrt{s} = 189$ GeV ($192 - 196$ GeV update discussed later...)

Standard Model Higgs

3 stage procedure for all analyses:

- Hadronic preselection (b/c of $\mathrm{q\bar{q}}$ in all final states)
- Tighter set of cuts specific to topology in question
- Final discriminant (including mass information): purity, likelihood, weighted prob., neural network output, reconstructed $(m_{\mathrm{h}}, m_{\mathrm{A}})$

Three possible dijet pairings in a four-jet event



$m_1 = m(j_1, j_2)$
$m_1' = m(j_3, j_4)$

$m_2 = m(j_1, j_3)$
$m_2' = m(j_2, j_4)$

$m_3 = m(j_1, j_4)$
$m_3' = m(j_2, j_3)$

For the $\mathrm{hZ} \rightarrow \mathrm{b\bar{b}q\bar{q}}$ analysis, the following mass χ^2 variables are defined:

$$\chi^2(m_\mathrm{Z}, m_\mathrm{h}) =$$

$$\min \quad (\Sigma_i - (m_\mathrm{Z} + m_\mathrm{h}))^2 w_\Sigma + (\Delta_i - |m_\mathrm{Z} - m_\mathrm{h}|)^2 w_\Delta$$

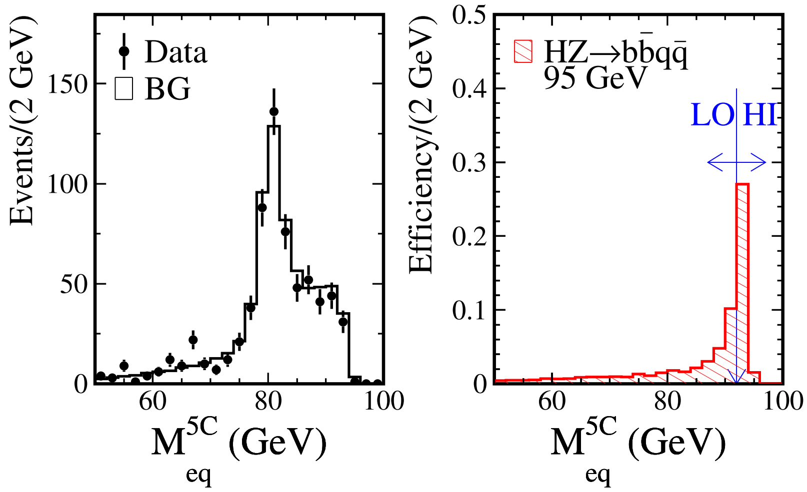
$$\chi_{\mathrm{hZ}} = \log P \quad \chi^2(m_\mathrm{Z}, m_\mathrm{h}) \quad .$$

- Index i runs over 3 dijet pairings.
- Σ_i and Δ_i are the sum and difference of the dijet pair, (m_i, m_i').
- w_Σ and w_Δ, are respectively $1/(4\ \mathrm{GeV})^2$ and $1/(6\ \mathrm{GeV})^2$, reflecting the typical mass resolutions.

SM $\mathrm{hZ} \to \mathrm{b\bar{b}q\bar{q}}$ Search

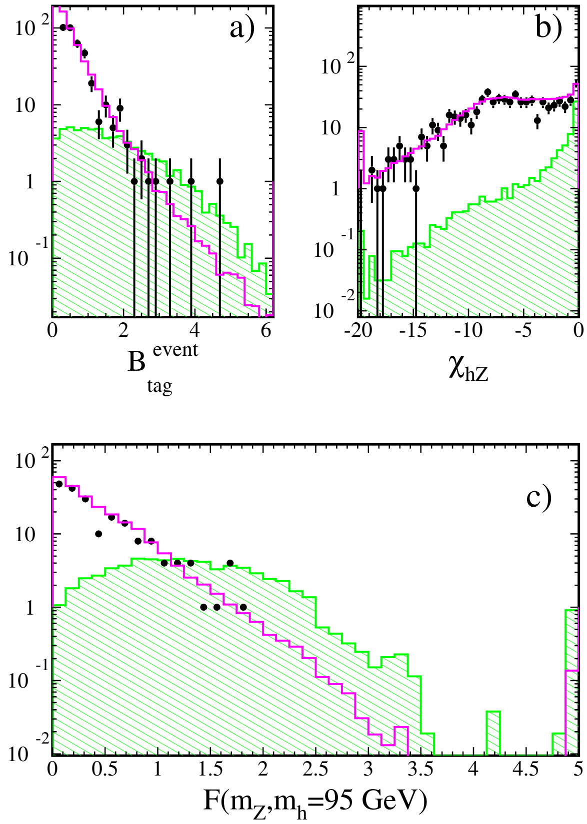
Signal: 4 jets, b quarks, $M_{q\bar{q}} \approx m_Z$
Background: 4 jet QCD, hadronic $\mathrm{W^+W^-}$ & ZZ

- *Preselection:* High multiplicity hadronic events, Large E_{vis}
- *Optimized cuts:* Maximize $< CL >$ by automatically (MINUIT) adjusting kinematic cuts. Kills mostly $\mathrm{q\bar{q}+gluons}$.
- After optimized cuts: 682 data, 703 BG with 85% $\mathrm{W^+W^-}$
- Hadronic $\mathrm{W^+W^-}$ events have
  - low b-tags
  - dijet masses $\approx m_W$
- Split sample into Low/High purity samples using sliding cut on M_{eq}^{5C}:



SM $\mathrm{hZ} \rightarrow \mathrm{b\bar{b}q\bar{q}}$ Search

The Final Variable



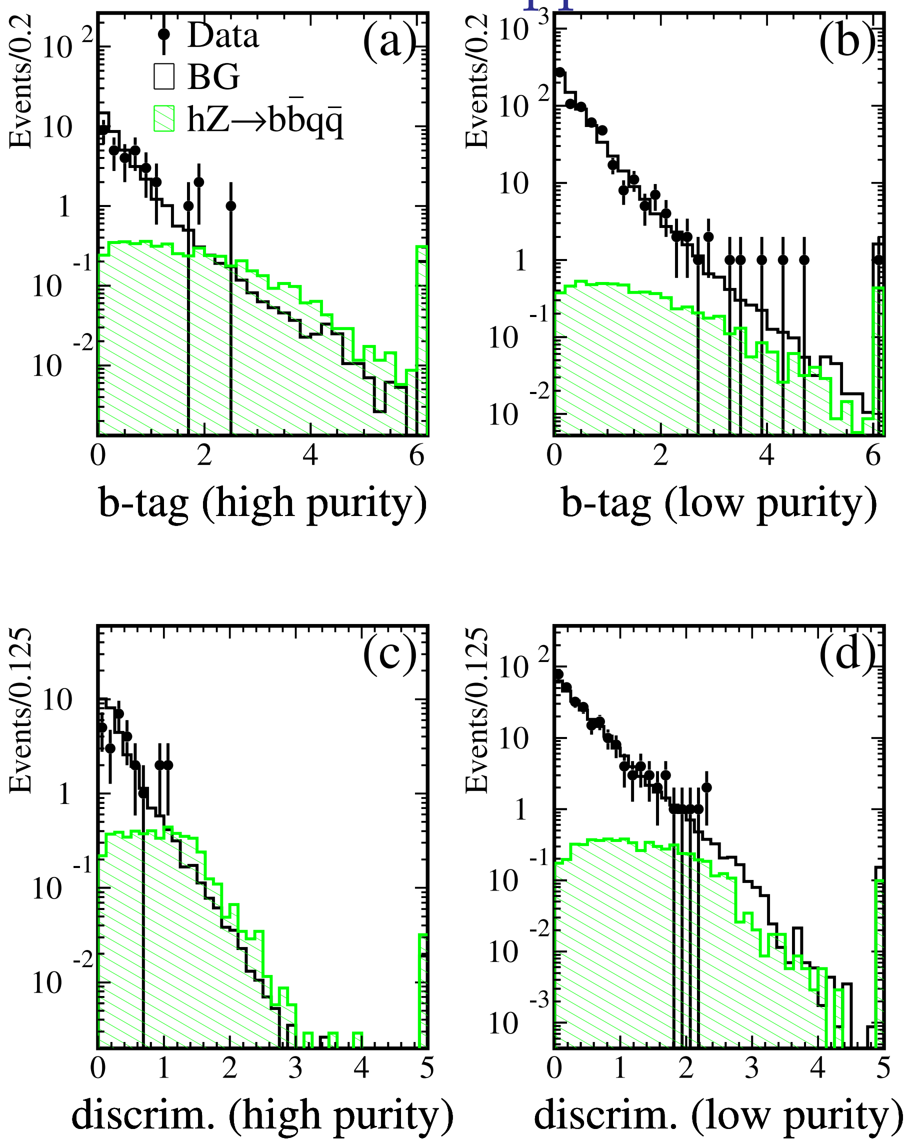
a) $B^{\text{event}}_{\text{tag}}$ for 189 GeV data, background and $100\times$ $\mathrm{hZ} \rightarrow \mathrm{b\bar{b}q\bar{q}}$ signal efficiency.

b) Mass variable, χ_{hZ} for $m_{\text{h}} = 95$ GeV.

c) Combined $B^{\text{event}}_{\text{tag}}$ and χ_{hZ} into final mass dependent variable, F.

- Basic idea: Instead of making tight cuts, use entire spectrum of most powerful variables $B^{\text{event}}_{\text{tag}}$, χ_{hZ}.
- Use same weighted probability combination technique used in b-tagging to combine $B^{\text{event}}_{\text{tag}}$ and χ_{hZ} probabilities.
- Depends on mass hypothesis!

SM $hZ \rightarrow b\bar{b}q\bar{q}$ Search



Final var. is weighted combo of $B_{\mathrm{tag}} \times \mathrm{Mass}$

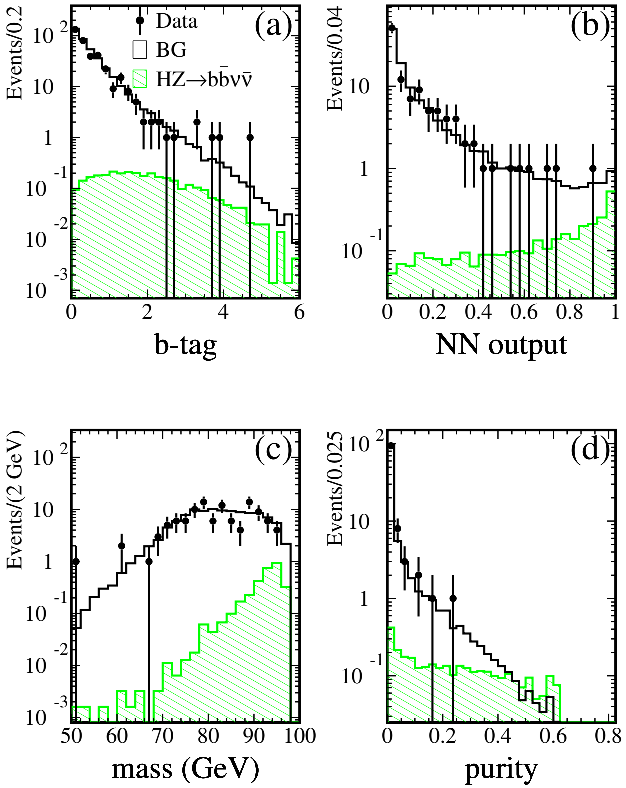
- HI: $B_{\mathrm{tag}} > 0.09 \Rightarrow$ 26 data, 31 BG, 28% eff. for 95 GeV
- LO: $B_{\mathrm{tag}} > 0.41 \Rightarrow$ 263 data, 239 BG, 34% eff. for 95 GeV

SM $hZ \to b\bar{b}\nu\bar{\nu}$ Search

Signal: 2 jets, b quarks, $M_{\mathrm{miss}} \approx m_Z$

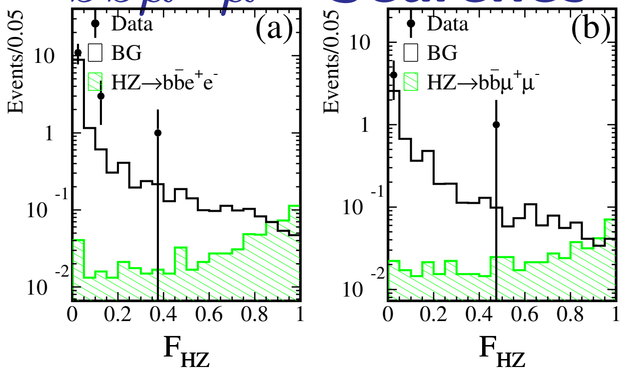
Background: 2 jet QCD, semileptonic W^+W^-, $ZZ \to q\bar{q}\nu\bar{\nu}$

- *Preselection:* Hadronic events with missing energy
- *Selection:* High eff. on signal to train neural network
  - Train mass-independent neural network to identify $hZ \to b\bar{b}\nu\bar{\nu}$
  - Use a cocktail of various signal masses
  - Can't train NNet on very tricky ZZ background!
- Final var. is purity from M_H^{5C} and NNet for given mass hypothesis.



109 Data, 116 BG and 62% eff. for 95 GeV

SM $\mathrm{hZ}\rightarrow \mathrm{b\bar{b}e^+e^-}$, $\mathrm{hZ}\rightarrow \mathrm{b\bar{b}}\mu^+\mu^-$ Searches



Signal: 2 high energy $\mathrm{e}^\pm$ or $\mu^\pm$, 2 b jets, $M_{\mathrm{lep}} \approx m_{\mathrm{Z}}$

- *Preselection:* Hadronic events + leptons
- *Selection:* High eff. to build likelihood as final variable
- This is a low rate channel, but very clean, efficient and would be nice for m_{h} measurement!

- 3 input variables: $i = (B_{\mathrm{jet1}}, B_{\mathrm{jet2}}, M_{\mathrm{H}}^{5\mathrm{C}})$
- 5 event classes: $j = (\mathrm{ZZ}, \mathrm{W^+W^-}, \mathrm{q\bar{q}}, \mathrm{Ze^+e^-}, \mathrm{hZ})$
- f_j^i prob. density of var. i for event class j
- $p_j^i = f_j^i / \sum_k f_k^i$ prob. to belong to j based on i

Likelihood for event to be hZ

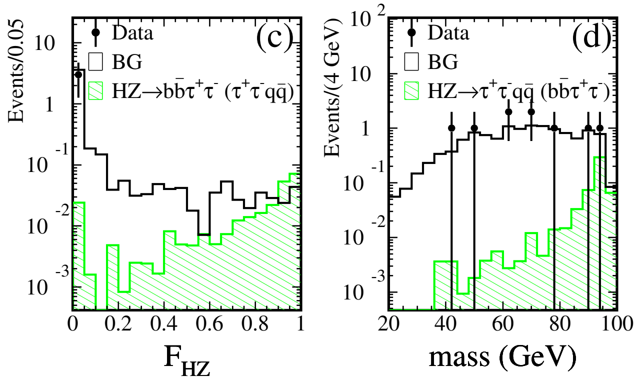
$$F_{\mathrm{hZ}} = \prod_i p_{\mathrm{hZ}}^i / \sum_k \prod_i p_k^i$$

$\mathrm{e^+e^-}$: 15 data, 13.2 BG, 77% eff $\mu^+\mu^-$: 5 data, 5.5 BG, 57% eff

SM $hZ \to b\bar{b}\tau^+\tau^-$, $hZ \to \tau^+\tau^- q\bar{q}$ Searches

Signal: Taus + jets. Very similar final states!

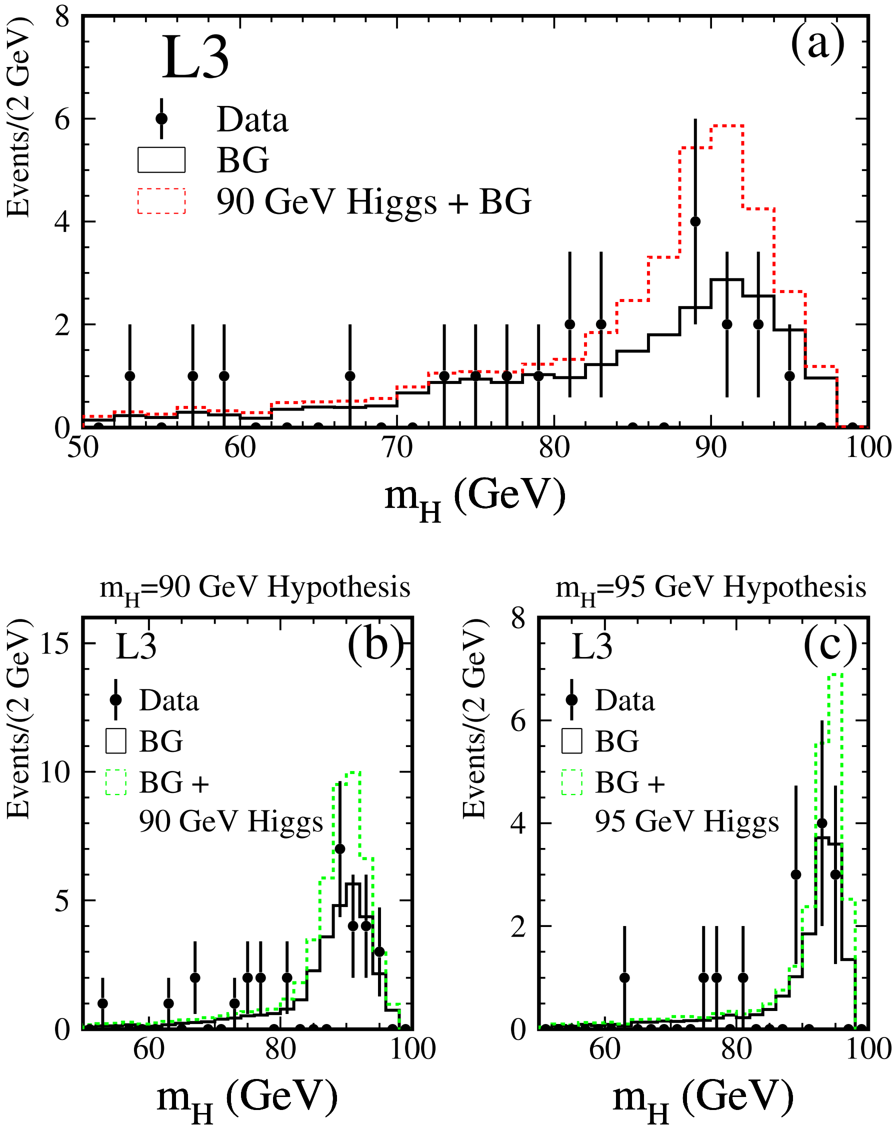
- *Preselection:* Hadronic events, $E_{e,\mu} \leq 40$ GeV to reject semileptonic W^+W^-
- *τ-id:* particle-based *OR* jet-based
  - Challenging channel!
  - particle-based: decay into e or μ or isolated jet with 1,3 tracks and $Q = 1$.
  - jet-based: Force event into 4-jets. Must have 2 jets with < 4 tracks.



- $hZ \to b\bar{b}\tau^+\tau^-$: $M_{\tau\tau}$ consistent with m_Z
- $hZ \to \tau^+\tau^- q\bar{q}$: $M_{\mathrm{jet-jet}}$ consistent with m_Z
- Significant cross-efficiency ($\sim 30\%$).
- Events passing both selections assigned to channel with largest F_{hZ}.

12 data, 17.1 BG, 30% eff for both $b\bar{b}\tau^+\tau^-$ and $\tau^+\tau^- q\bar{q}$

SM Combined Results



(a) Higgs mass after *mass-independent* selections (high B_{tag}, large NNet)

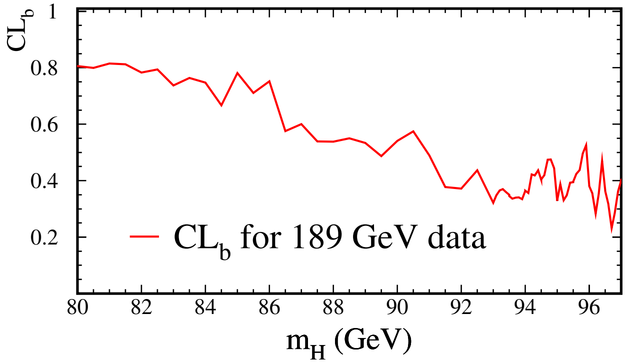
(b-c) After cut on *mass-dependent* final variables ($S/B > 0.25$).

Confidence Levels

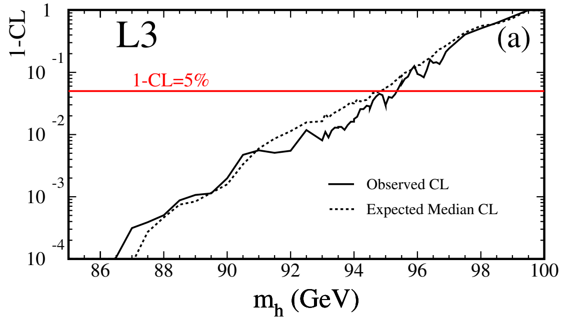
- Confidence Levels used to optimize the analyses and to draw conclusions about the presence of a signal.
- Use binned spectra of final variable for data, background, signal hypothesis.
- Allows us to easily combine results from: $\mathrm{hZ} \to \mathrm{b\bar{b}q\bar{q}}$, $\mathrm{hZ} \to \mathrm{b\bar{b}}\nu\bar{\nu}$, $\mathrm{hZ} \to \mathrm{b\bar{b}}\ell^+\ell^-$, $\mathrm{hZ} \to \tau^+\tau^-\mathrm{q\bar{q}}$.
- CL_b quantifies the consistency of this final spectrum from observed data and a background only hypothesis.
  - If data is perfectly consistent with background, then $CL_b \sim 50\%$.
  - Excess of data over expected background $\Rightarrow$ $CL_b \to 1$.
  - 3σ "Discovery" would have $CL_b \sim 99.7\%$.
- In absence of discovery, set confidence level to exclude this hypothesis: CL.

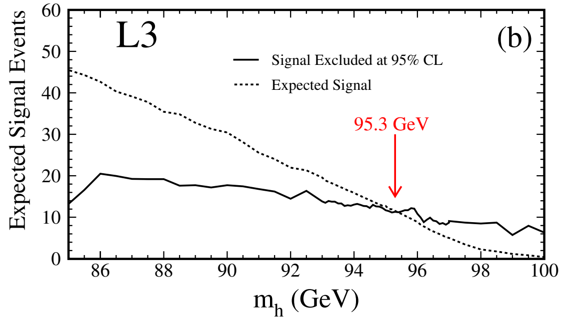
Combined Results

- Set lower limit on Standard Model Higgs mass using 189 GeV data at $m_{\mathrm{H}} > 95.3\ \mathrm{GeV}$ at 95% CL



- Mass dependent test of consistency of 189 GeV data with background
- No large values of CL_b $\Rightarrow$ no clear excess anywhere





UPDATE SM Search at $192 - 196$

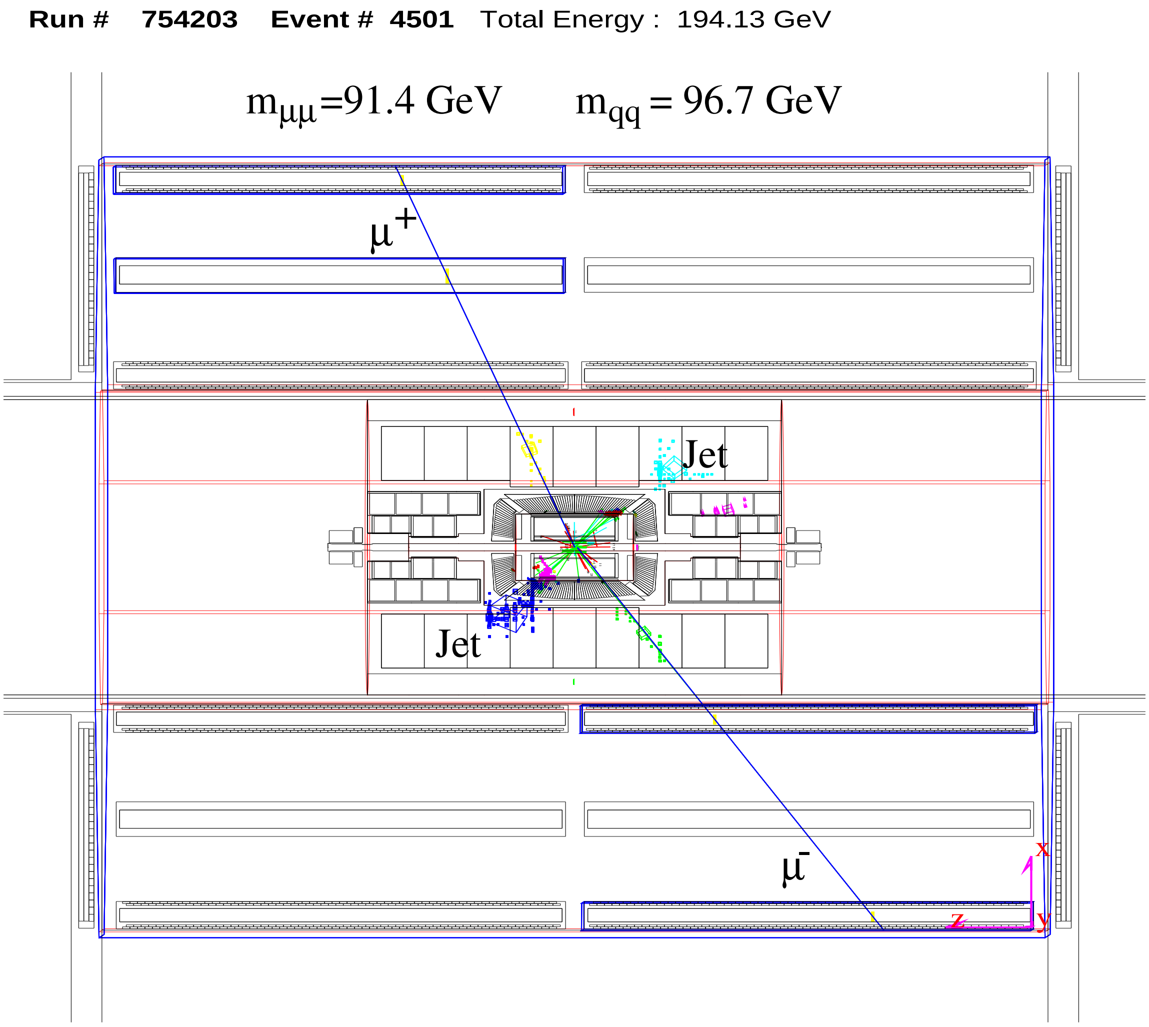
- 189 GeV search now finalized (accepted by Phys. Lett. B)

- LEP running this year at ever increasing beam energies with *excellent* lumi:
  - $\sqrt{s} = 192$ GeV $\Rightarrow$ 29.2 pb^{-1}
  - $\sqrt{s} = 196$ GeV $\Rightarrow$ 81.4 pb^{-1}
  - $\sqrt{s} = 200$ GeV $\Rightarrow$ 35 pb^{-1} and still rolling in!

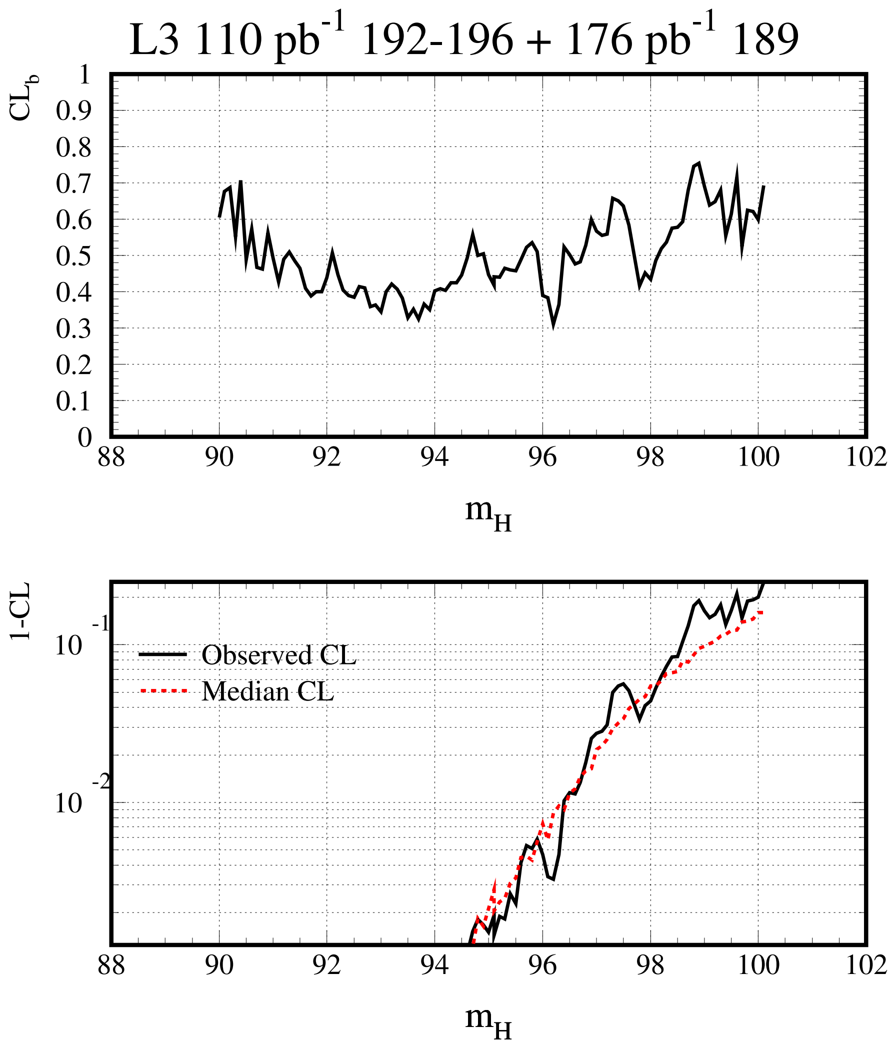
- Preliminary update of SM Higgs search using $192 + 196$ GeV data:
  - $\mathrm{hZ} \rightarrow \mathrm{b\bar{b}q\bar{q}}$
  - $\mathrm{hZ} \rightarrow \mathrm{b\bar{b}}\nu\bar{\nu}$
  - $\mathrm{hZ} \rightarrow \mathrm{b\bar{b}}\ell^+\ell^-$ ($\ell = \mathrm{e}, \mu$)

UPDATE SM Search at $192 - 196$

$\mathrm{hZ} \rightarrow \mathrm{b\bar{b}}\mu^{+}\mu^{-}$ candidate at $\sqrt{s} = 196$ GeV



UPDATE SM Search at $192 - 196$



No evidence of signal! $m_{\mathrm{H}} > 97.3$ GeV

See Pete McNamara's talk tomorrow on LEP combined results at $192 - 196$ GeV...

Benchmarks

- All 4 LEP experiments consider "restricted version" of MSSM (6 free parameters other than SM parameters).

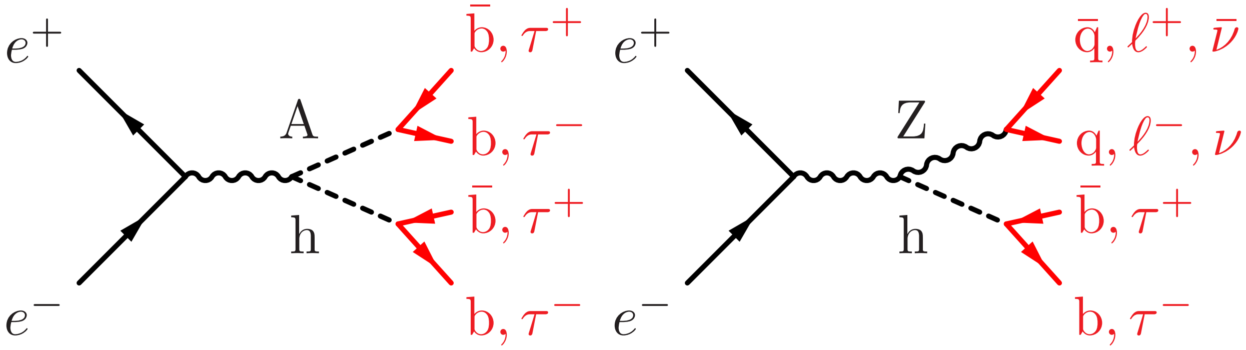
- Benchmark parameter values agreed upon for comparisons during LEP 2 workshop in '95 (caveat: new partial 2-loop calculations?)
  - Minimal Mixing: $A = 0$, $\mu = -1$ TeV, $M_2 = m_0 = 1$ TeV.
  - Maximal Mixing: $A = \sqrt{6}$ TeV, $\mu = -0.1$ TeV, $M_2 = m_0 = 1$ TeV. Also $m_\mathrm{t} = 175$ GeV.

- We scan over $\tan\beta$ and m_A and use predicted m_h.

- Restrict possibility of decays into SUSY particles, but allow for $\mathrm{h} \rightarrow \mathrm{AA}$.

$\Rightarrow$ This sets the experimental program.

MSSM Higgs



- Now, in addition to SM-like hZ channels, we have $\mathrm{hA} \rightarrow \mathrm{b\bar{b}b\bar{b}}, \mathrm{b\bar{b}}\ \tau^+\tau^-$.
- Relative rates of $\mathrm{e^+e^-} \rightarrow \mathrm{Z}^* \rightarrow \mathrm{hZ}$ and $\mathrm{e^+e^-} \rightarrow \mathrm{Z}^* \rightarrow \mathrm{hA}$ change as a function of $\tan\beta$.
- Otherwise, the signal characteristics are very much the same as in Standard Model Higgs search.
- Use exactly the same preselection, and independently optimize same kinematic variables.
- $B_{\mathrm{tag}}^{\mathrm{event}}$ is more important for $\mathrm{hA} \rightarrow \mathrm{b\bar{b}b\bar{b}}$ than for $\mathrm{hZ} \rightarrow \mathrm{b\bar{b}q\bar{q}}$.
- Define another mass variable to be: $\chi_{\mathrm{hA}} = \log P \quad \chi^2(m_{\mathrm{A}}, m_{\mathrm{h}})$
- Data set: 176.4 pb^{-1} at $\sqrt{s} = 189$ GeV

MSSM Higgs

Choosing between $\mathrm{hZ} \to \mathrm{b\bar{b}q\bar{q}}$ and $\mathrm{hA} \to \mathrm{b\bar{b}b\bar{b}}$

- Relative rate of $\mathrm{e^+e^-} \to \mathrm{Z}^* \to \mathrm{hZ}$ and $\mathrm{e^+e^-} \to \mathrm{Z}^* \to \mathrm{hA}$ depends on $\tan\beta$.
- Events passing optimized hZ or hA cuts are put into 3 categories:
  1. Events passing only hZ cuts ($\mathrm{hZ_{b\bar{b}q\bar{q}}}$).
  2. Events passing only hA cuts ($\mathrm{hA_{b\bar{b}b\bar{b}}}$).
  3. Events passing both hZ and hA cuts.
- Events in category 3 are split according to most likely production hypothesis:

If $\sigma_{\mathrm{hZ}\to\mathrm{b\bar{b}q\bar{q}}} P\left(\chi^2(m_\mathrm{Z}, m_\mathrm{h})\right)$

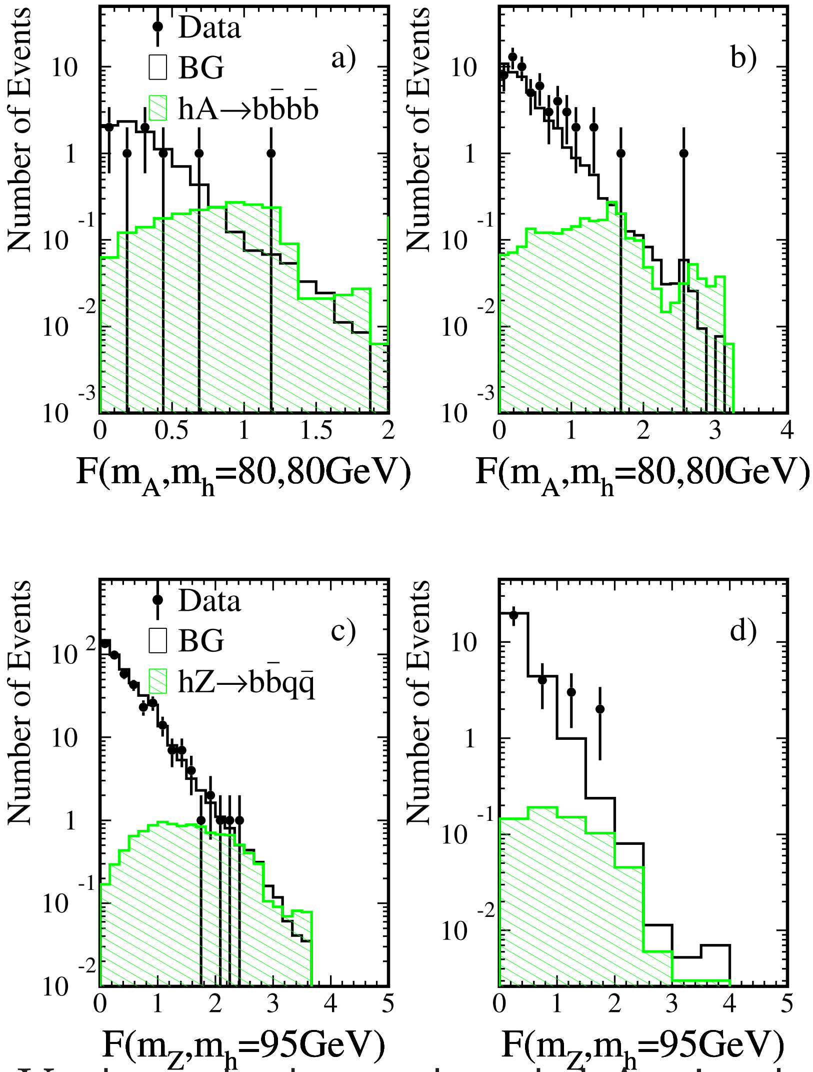
$$> \sigma_{\mathrm{hA}\to\mathrm{b\bar{b}b\bar{b}}} P\left(\chi^2(m_\mathrm{A}, m_\mathrm{h})\right)$$

Then event considered $\mathrm{hZ} \to \mathrm{b\bar{b}q\bar{q}}$ ($\mathrm{hZ'_{b\bar{b}q\bar{q}}}$)

Else $\mathrm{hA} \to \mathrm{b\bar{b}b\bar{b}}$ ($\mathrm{hA'_{b\bar{b}b\bar{b}}}$)

MSSM Higgs

The Final Variable



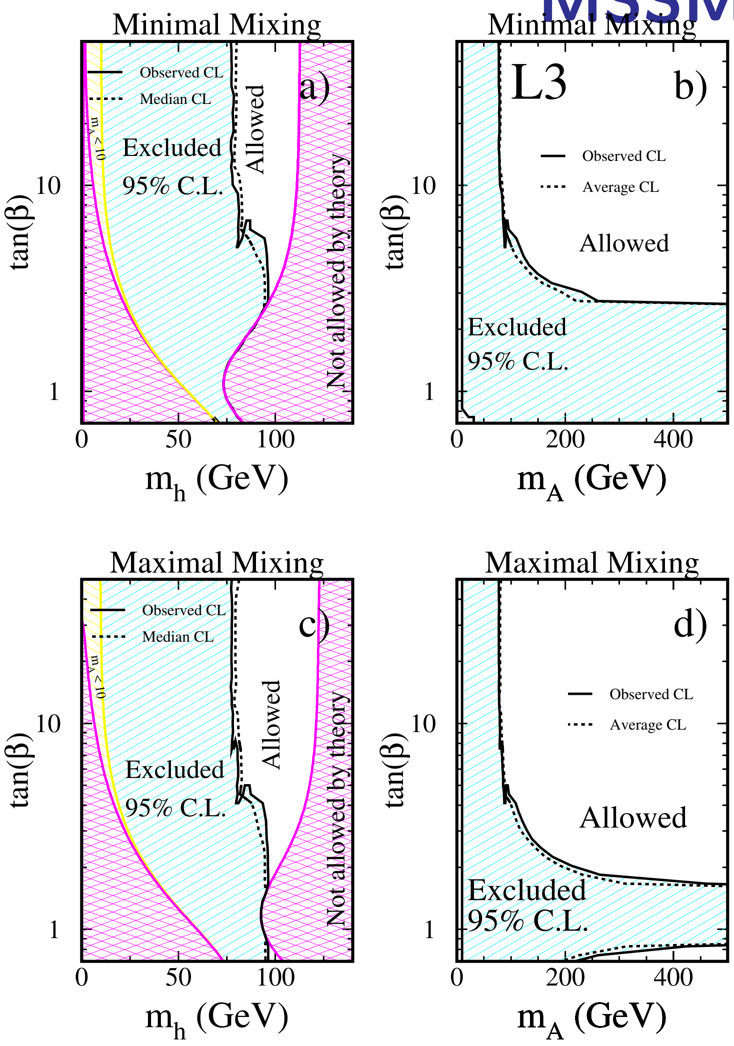
a) $189\ \mathrm{GeV}$ data, background and hA signal for $\mathrm{hA}_{\mathrm{b\bar{b}b\bar{b}}}$ analysis.

b) $\mathrm{hA}'_{\mathrm{b\bar{b}b\bar{b}}}$ analysis.

c) $\mathrm{hZ}'_{\mathrm{b\bar{b}q\bar{q}}}$ analysis for hZ signal.

d) $\mathrm{hZ}_{\mathrm{b\bar{b}q\bar{q}}}$ analysis

MSSM Higgs



- Some candidates around m_{W} in $\sqrt{s} = 189$ GeV data, but no clear evidence of signal.

- $m_{\mathrm{h}} > 77.1$ GeV, $m_{\mathrm{A}} > 77.1$ GeV at 95% CL using data at $\sqrt{s} = 189$ combined with lower $\sqrt{s}$ searches.

- $\tan\beta$ excluded between 0.8 and 1.5 at the 95% CL, but this depends on m_{t} and the accuracy of the theoretical upper bounds on m_{h}.

Charged Higgs

- Signal Definition: $e^+e^- \to Z/\gamma \to H^+H^-$. Consider tau and charm decays of $H^\pm$.

- Backgrounds: $q\bar{q}$, 2-photon, Z-pair and W-pair. W-pair is very difficult.

- Data set: Used $176.4\ \mathrm{pb}^{-1}$ collected at $189\ \mathrm{GeV}$.

- MSSM "forbids" $m_{H^\pm}$ in mass range accessible $\Rightarrow$ Do model independent search as a function of $m_{H^\pm}$ and $\mathrm{Br}(H^+ \to \tau^+\nu_\tau)$.

- Data set: $\sqrt{s} = 189\ \mathrm{GeV}$, 176.4 pb^{-1}. Combine with $\sqrt{s} = 130 - 183\ \mathrm{GeV}$ search.

Charged Higgs

$$\boxed{\mathrm{Z} \to \mathrm{H}^+\mathrm{H}^- \to \tau^+\nu_\tau\tau^-\bar{\nu}_\tau}$$

- Signal: Pair of taus with large missing energy, low multiplicity, low vis. energy events.

- Background: $\mathrm{W}^+\mathrm{W}^- \to \ell^+\nu\ell^-\bar{\nu}$, $\mathrm{e}^+\mathrm{e}^- \to \ell^+\ell^-$.

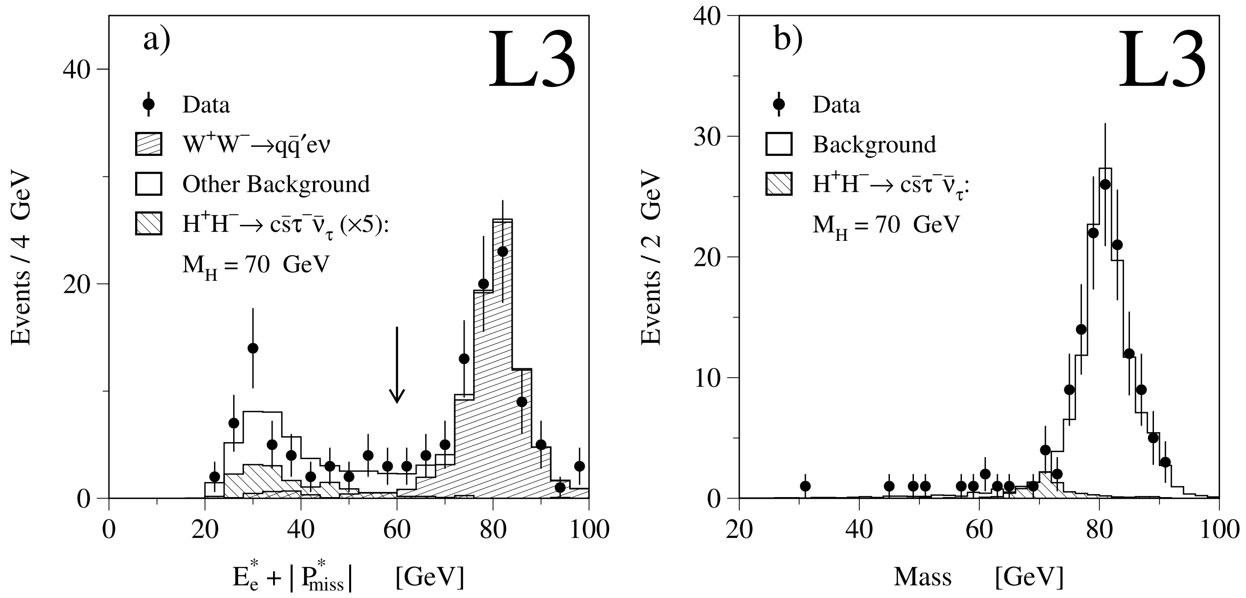
- Not possible to use reconstructed mass due to $\nu\bar{\nu}$ $\Rightarrow$ simple counting experiment.

Eff (%) for $m_{\mathrm{H}^\pm} =$ GeV				BG	DATA
60	65	70	75		
24	27	31	32	32.5	30

Charged Higgs

$$\boxed{\mathrm{Z} \to \mathrm{H}^+\mathrm{H}^- \to \tau^+\nu_\tau\bar{\mathrm{c}}\mathrm{s}\,(\bar{\mathrm{c}}\mathrm{s}\tau^-\bar{\nu}_\tau)}$$

- Signal: One tau with two high multiplicity jets and missing momentum.
- Background: $\mathrm{W}^+\mathrm{W}^- \to \mathrm{q}\bar{\mathrm{q}}\ell^-\bar{\nu}$, but $\mathrm{W}^+\mathrm{W}^- \to \mathrm{q}\bar{\mathrm{q}}\tau^-\bar{\nu}$ dominates.
- Final variable is avg. mass of jet-jet and $\tau\nu$ pairs.



138 Data, 129.3 BG and 40% eff. for 70 GeV.

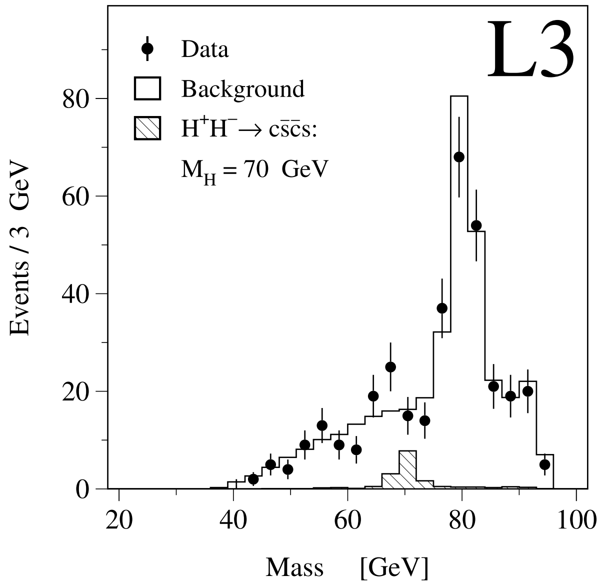
Charged Higgs

$$\boxed{Z \to H^+H^- \to c\bar{s}\bar{c}s}$$

- Signal: Four-jets, high multiplicity, large visible energy $\Rightarrow$ Just like $hZ \to b\bar{b}q\bar{q}$ but no $B^{\mathrm{event}}_{\mathrm{tag}}$.

- Background: Same as neutral Higgs 4-jets search, but W^+W^- is now irreducible!

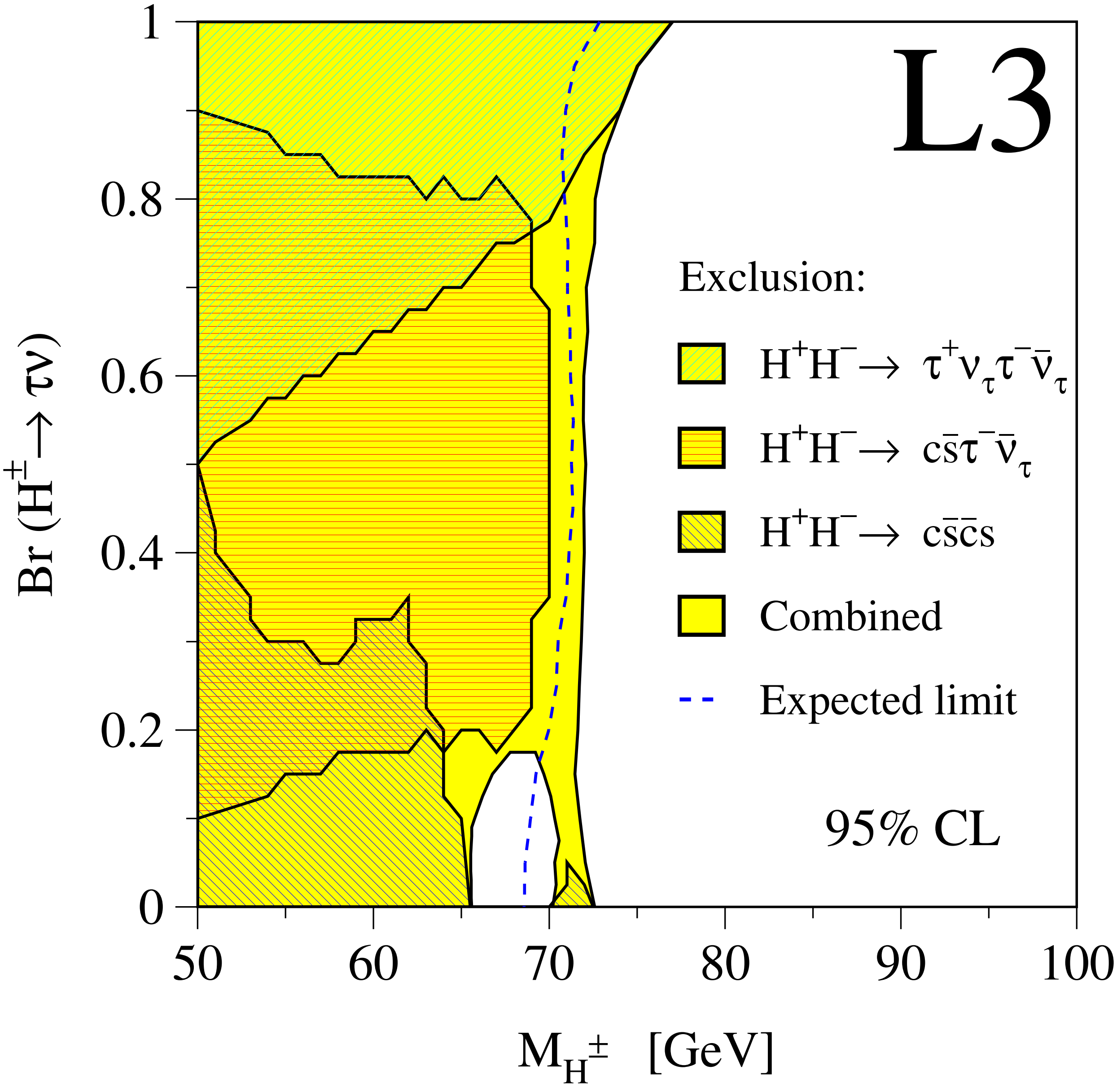
- Final variable is 5C mass.



348 Data, 359.4 BG and 38% eff. for 70 GeV.

Charged Higgs

No charged Higgs signal observed!



$$m_{\mathrm{H}^\pm} > 65.5 \text{ GeV}$$

Conclusions

$\boxed{\text{No Evidence of Signal!}}$

- Developed novel techniques to identify production of b quarks.

- These techniques would allow us to observe the Higgs boson through its decays into b quarks.

- No evidence of a neutral Higgs from the SM or (a restricted version) the MSSM found in the data collected by L3 at $\sqrt{s} = 189$ GeV. No evidence of SM Higgs in $\sqrt{s} = 192 - 196$ GeV data either.

- Also no evidence of charged Higgs in G2DM.

Systematic Errors

- Consider the effect on the number of expected background and signal events from:
  - Small uncertainties on LEP center-of-mass energy, luminosity measurement, theoretical uncertainties on calculated cross sections.
  - Larger uncertainties from normalization errors due to selection efficiencies (ie, cuts).
  - Limited MC statistics (Large, but uncorrelated bin-to-bin).
  - $\Rightarrow$ 5% error on signal, 10% error on background
  - Assumed to be fully correlated for all bins of a given channel.

- Account for these errors during MC calculation of CL by smearing final distributions in trials.

- Net effect usually small $\Rightarrow\sim 500$ MeV decrease in expected limit, more for discovery potential.