Higgs Searches in L3 and at LEP

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PhD Students Seminar October 3 - 5, 2000

- Motivation
- The L3 detector at LEP
- The Year 2000 data sample
- Signal and background processes
- HZ $\rightarrow$ qqqq in L3
- How to calculate confidence levels
- Combined L3 results
- Combined LEP results
- Conclusions

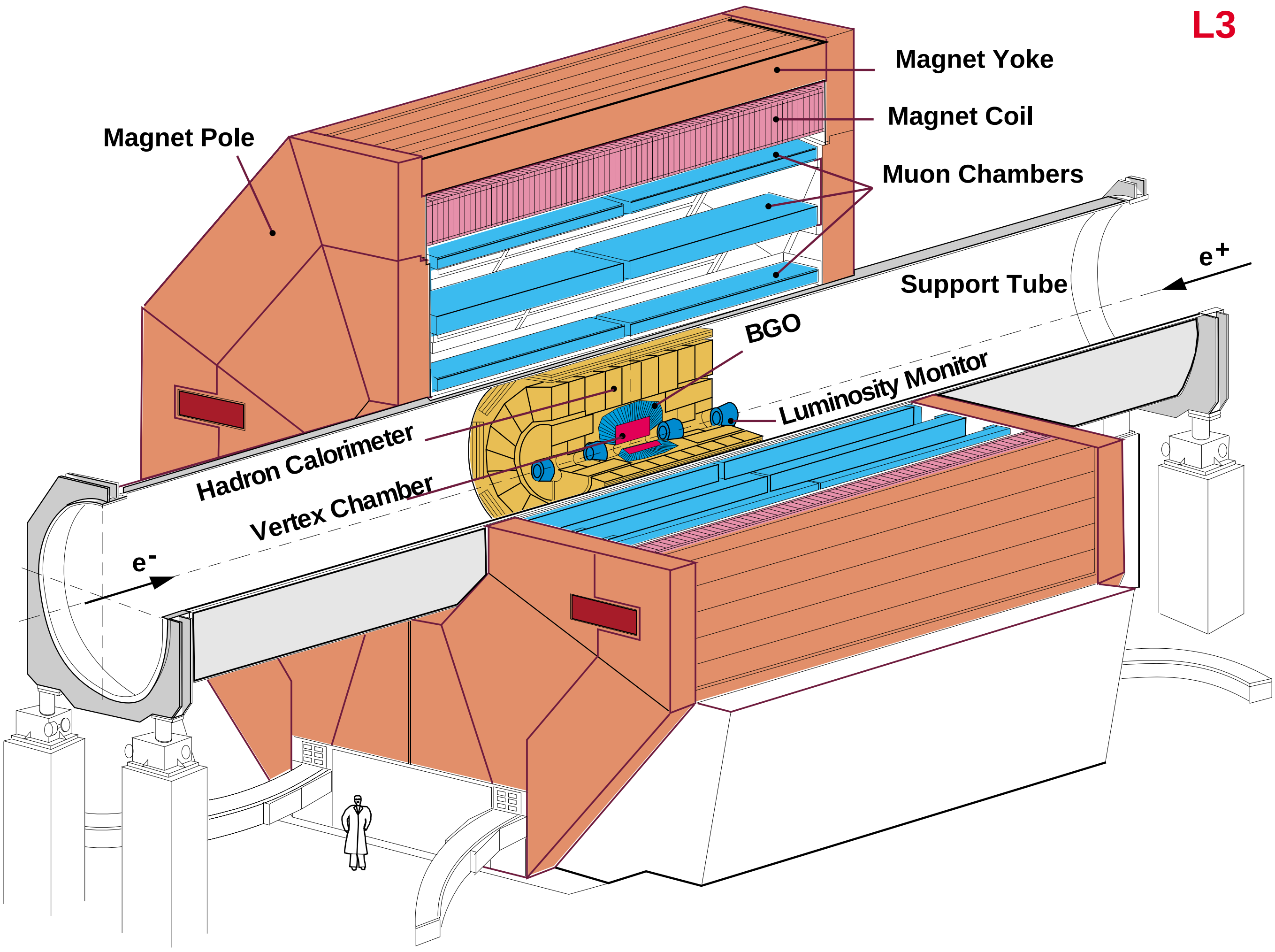
Why do we look for a Higgs field/particle ?

- The Lagrangian of the Standard Model of Electroweak interactions (SM) describes Particles with nonzero masses (the $W^{\pm}$, Z, quarks and Leptons)
- $\rightarrow$ divergences in all orders of the perturbation calculation (massive bosons in loops)
- The ground state ('vacuum') is not minimizing the energy because of mass terms in the Lagrangian
- Expand perturbation series around a different ground state which is an energy minimum
- Freedom to choose between several equivalent ground states $\rightarrow$ four new degrees of freedom
- Three are eaten up by the longitudinal $W^{\pm}$ and Z, one remains

the Higgs field

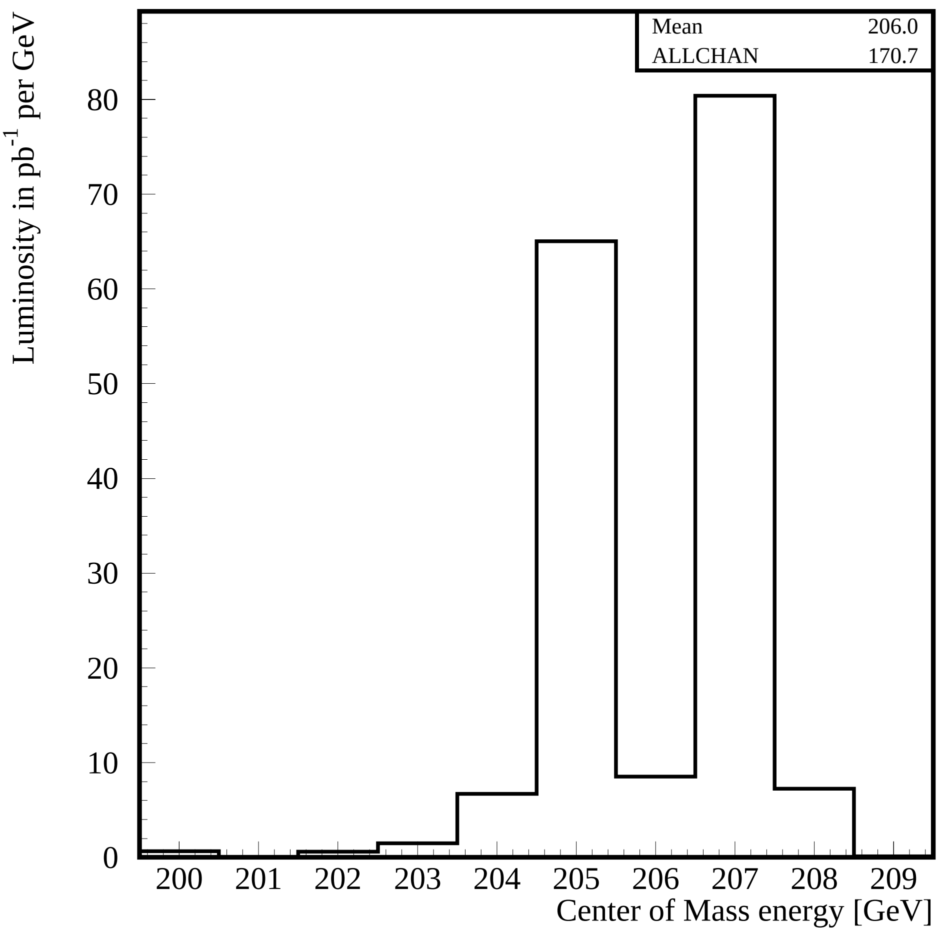
- This also keeps the cross section of the process $W^+W^- \rightarrow W^+W^-$ finite for large center of mass energies

The L3 detector at LEP



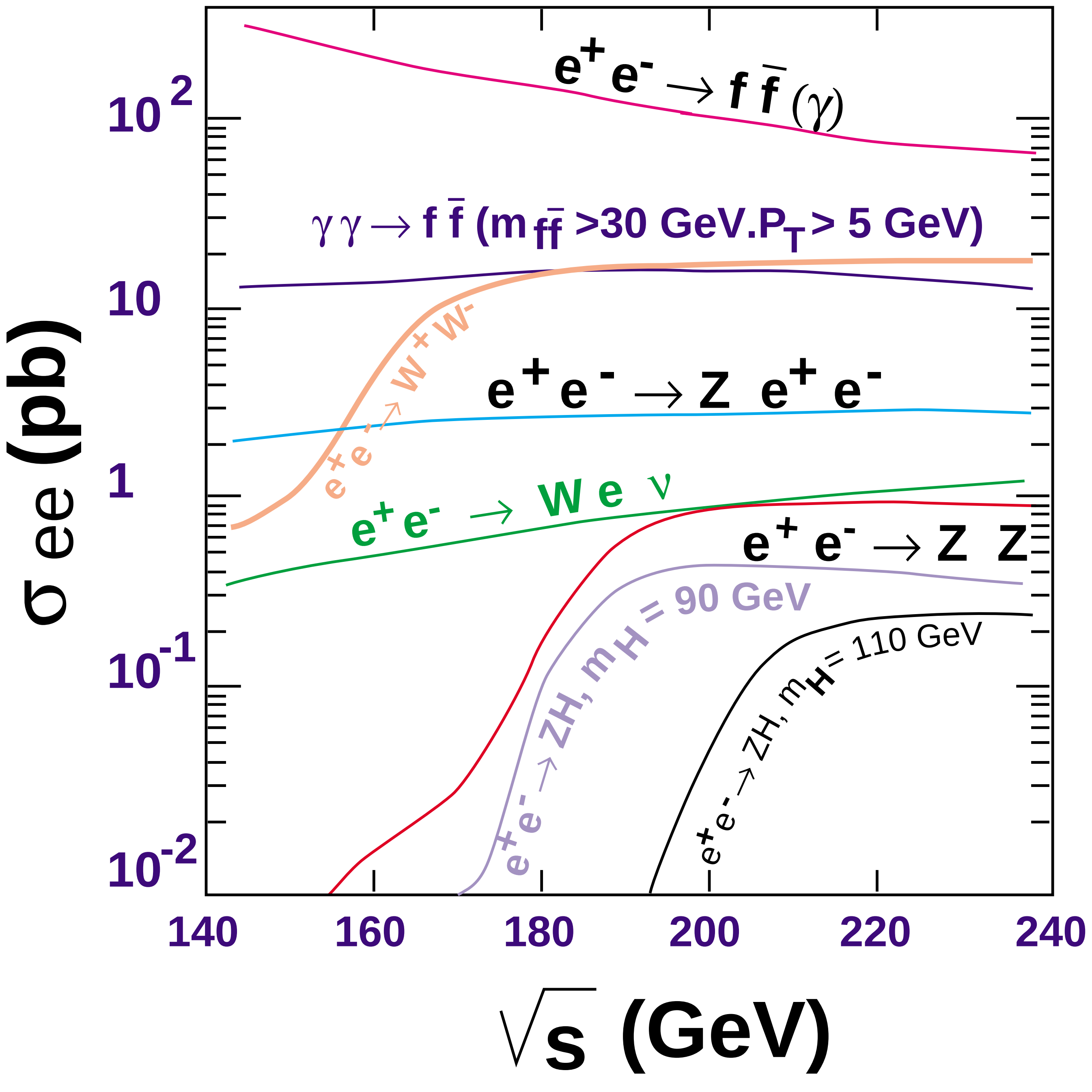
Year 2000 data sample

- Year 2000 L3 analyzed luminosity so far:



- 170.7/pb analyzed so far
- Excellent LEP performance
- Data is still coming in !

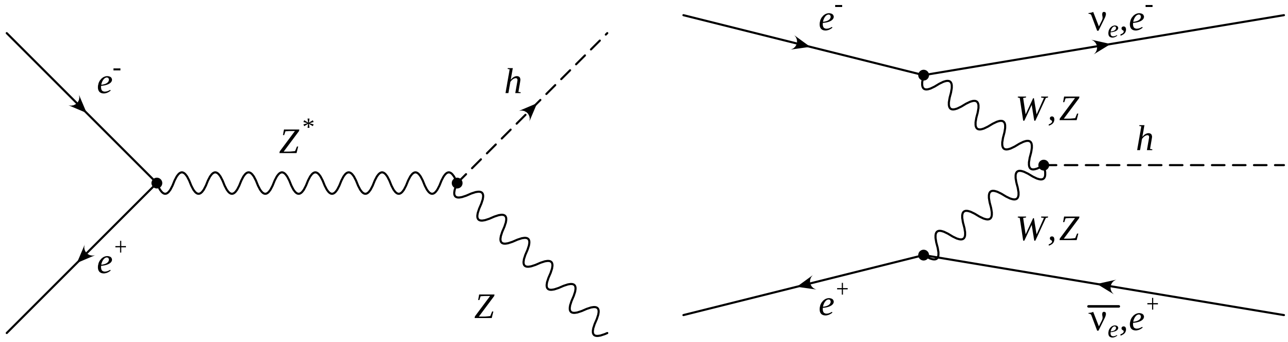
Most important background processes



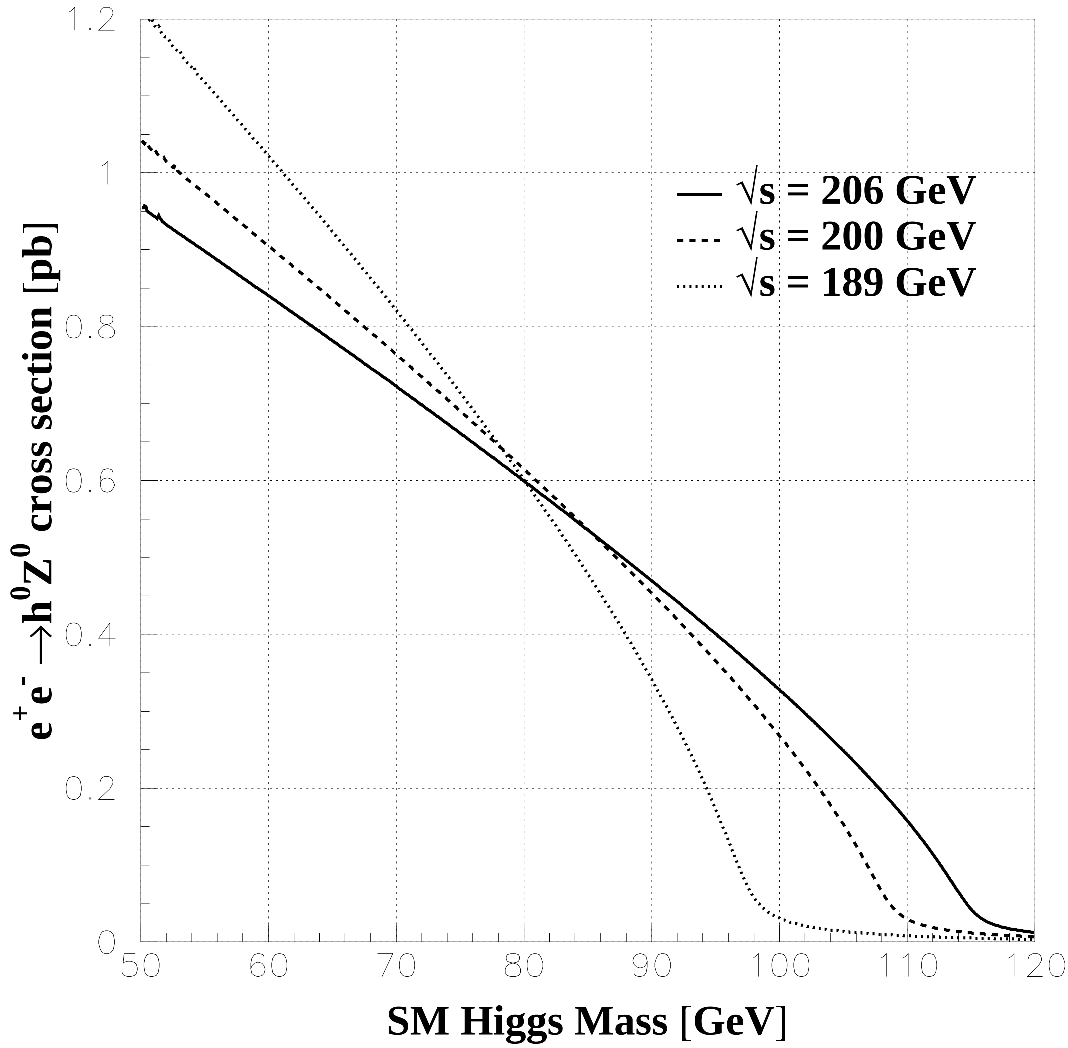
- $q\bar{q}(\gamma)$
- W and Z pair production
- Background cross sections up to two orders of magnitude higher than typical signal cross sections

How can Higgs Bosons be produced at LEP ?

- Dominant graphs: Higgs Strahlung and W/Z fusion



- Evolution of the cross section:

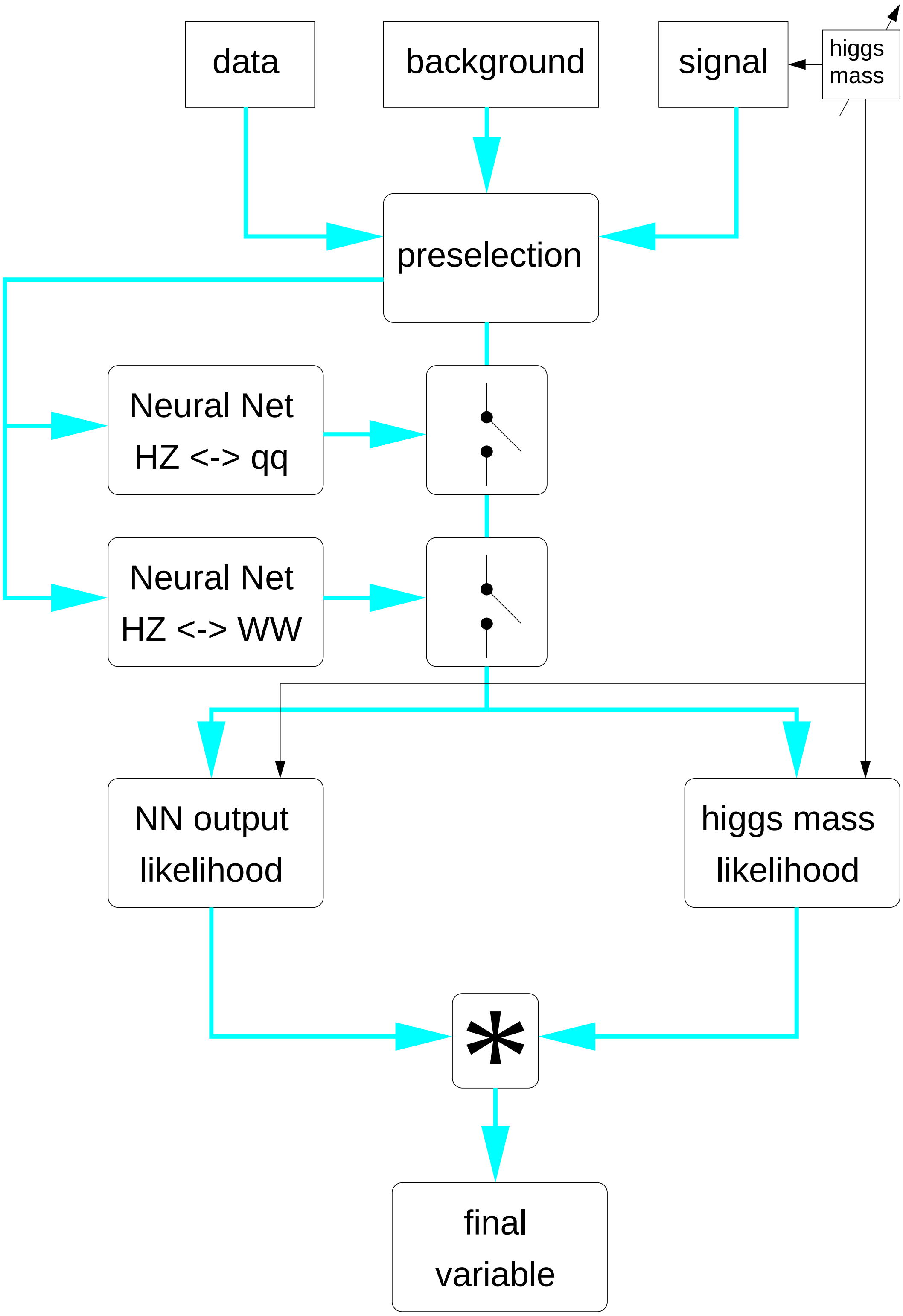


- Higgs decays mainly into a b quarks at masses of current interest

HZ → qqqq analysis in L3

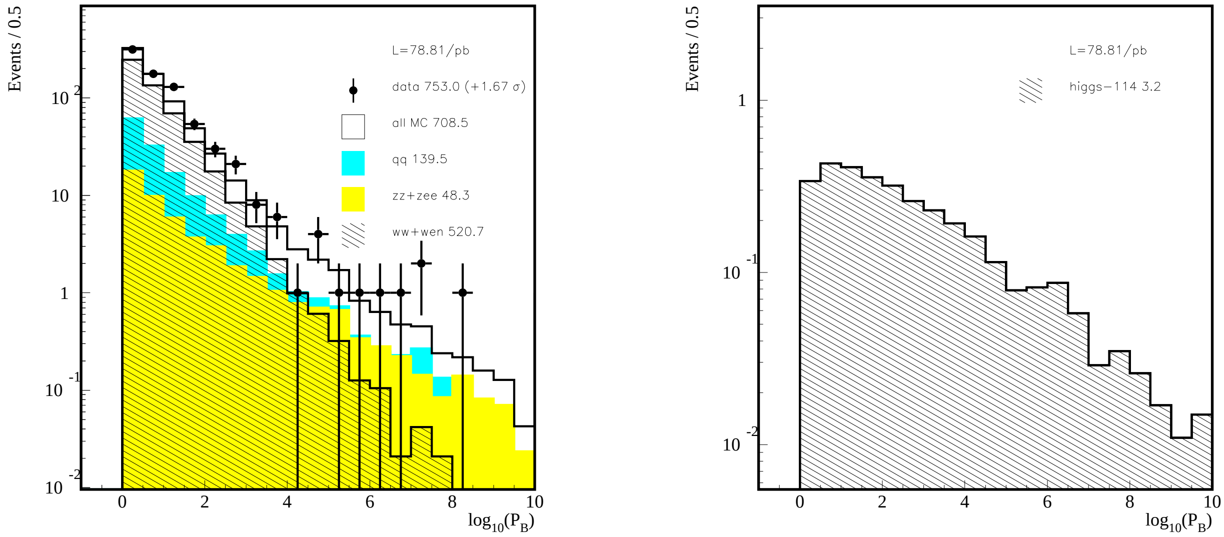
- Preselection to eliminate some backgrounds while keeping signal efficiency high (typ. 80%):
  - number of tracks ≥ 10
  - number of calorimetric clusters ≥ 20
  - perpendicular and transverse imbalance ≤ 0.3
  - visible energy $\geq 60\%$ of the Center of Mass Energy
  - effective center of mass energy $\geq 70\%$ of Center of Mass Energy
  - $log(Y_{34}^{\mathrm{Durham}}) \geq -5$
- Remaining backgrounds: $e^+e^- \to q\bar{q}, W^+W^-, ZZ$
- Two neural networks are trained to discriminate the HZ signal against the $q\bar{q}$ and WW background
- A final variable is constructed from the Neural network outputs and the reconstructed Higgs candidate mass

Flow of the HZ $\rightarrow$ qqqq Analysis

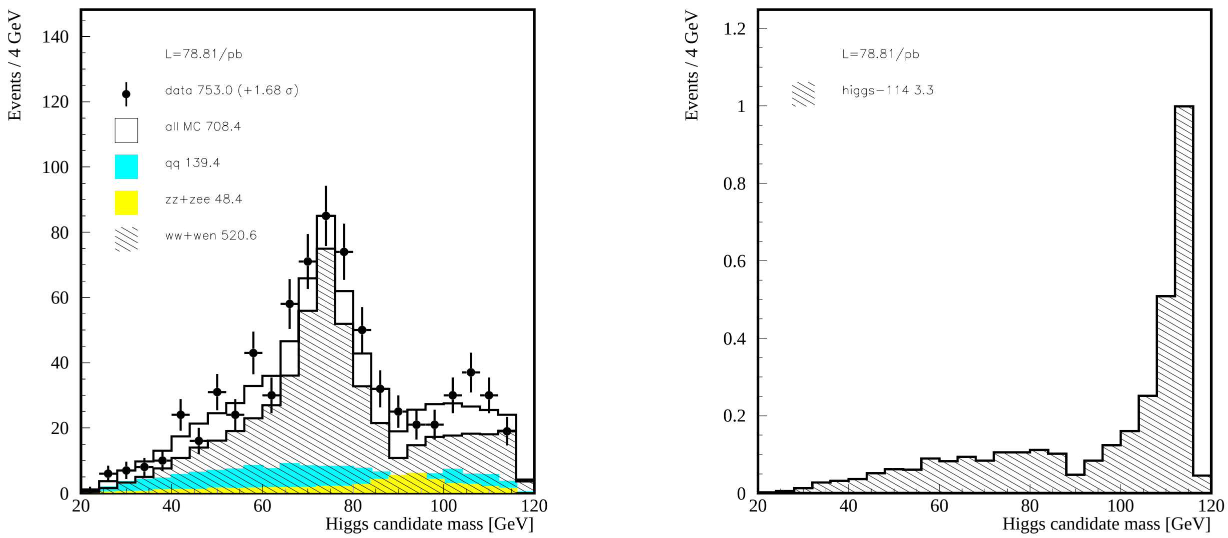


HZ → qqqq analysis in L3

B tag distribution after preselection



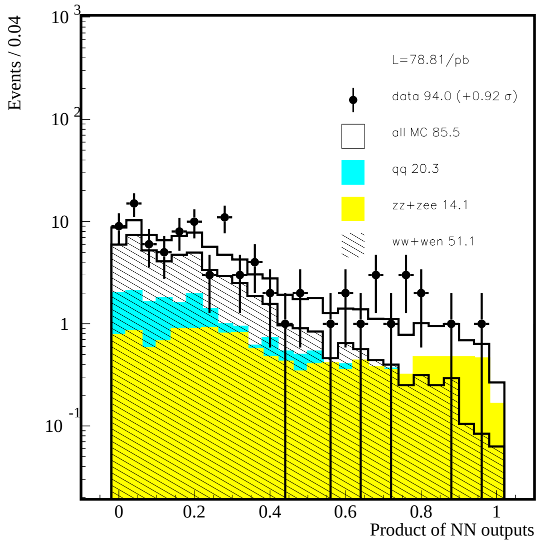
Reconstructed Higgs candidate mass distribution after preselection

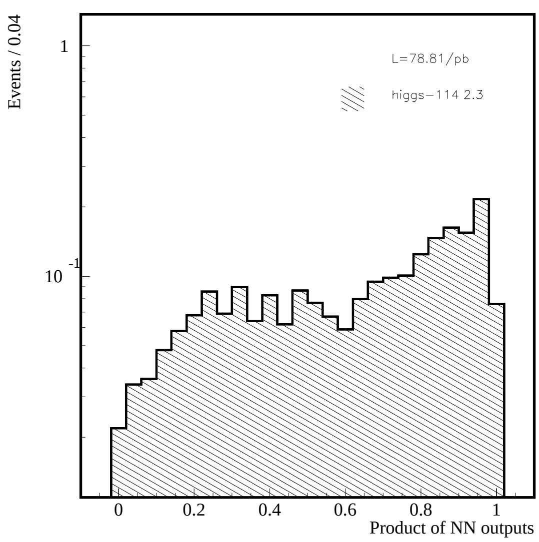


(Left: Background and Data, Right: Higgs for $m_H = 114$ GeV)

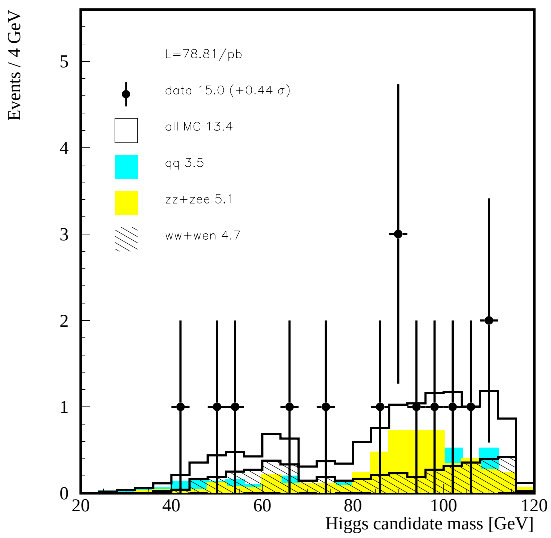
Analysis results

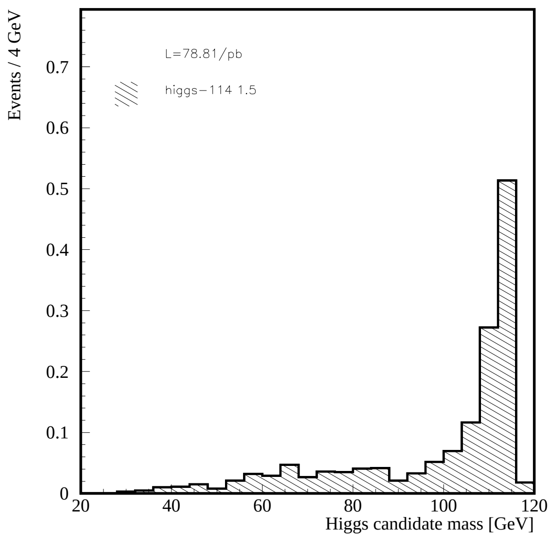
Product of anti $q\bar{q}$ and anti WW Networks after selection:





Reconstructed Higgs candidate mass distribution tight selection

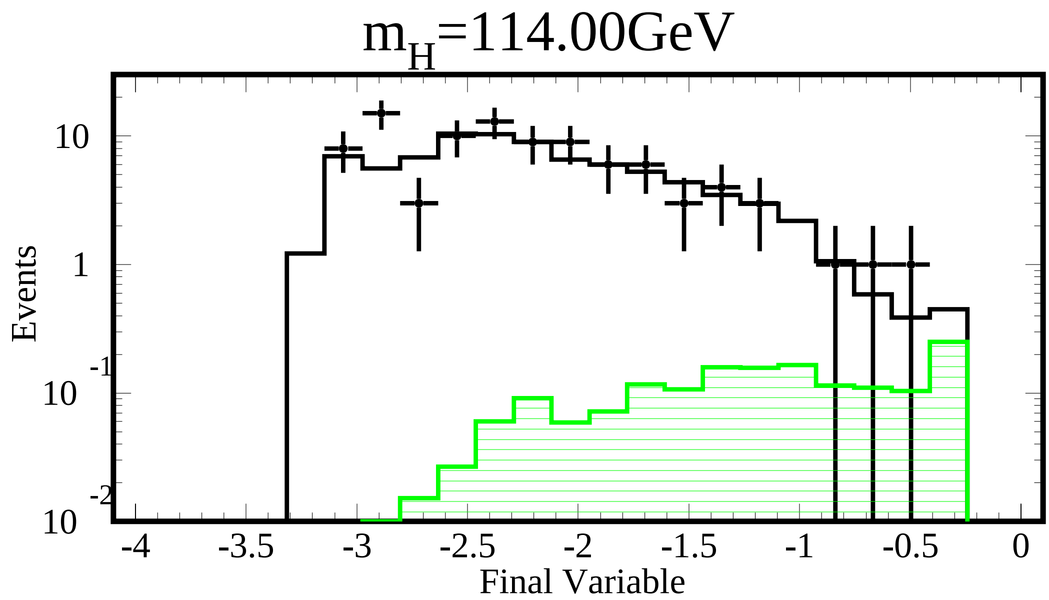




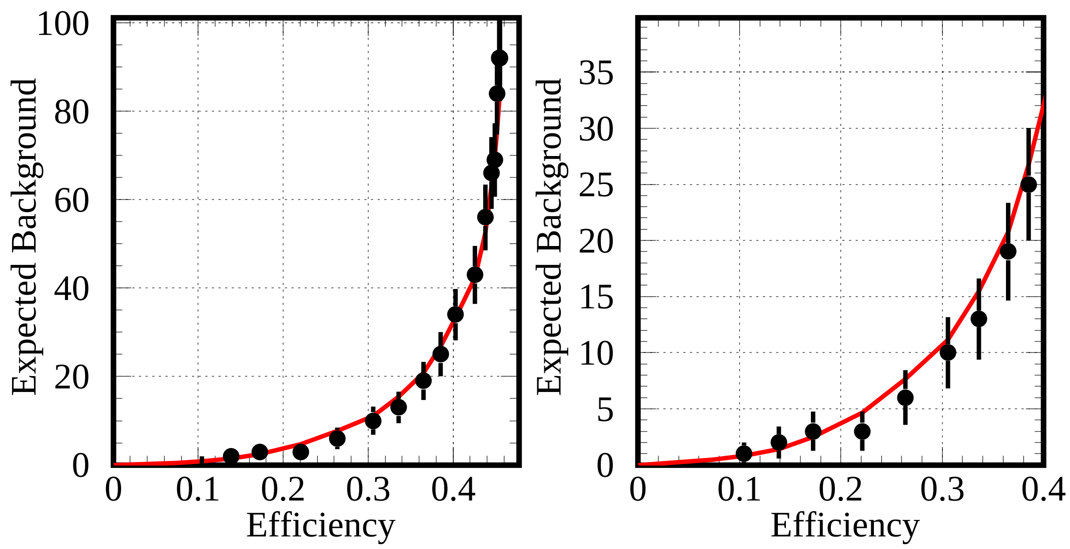
(Left: Background and Data, Right: Higgs for $m_H = 114$ GeV)

Results of the analysis

Final variable distribution (combination of mass and neural network output) for a Higgs mass hypothesis of 114 GeV:



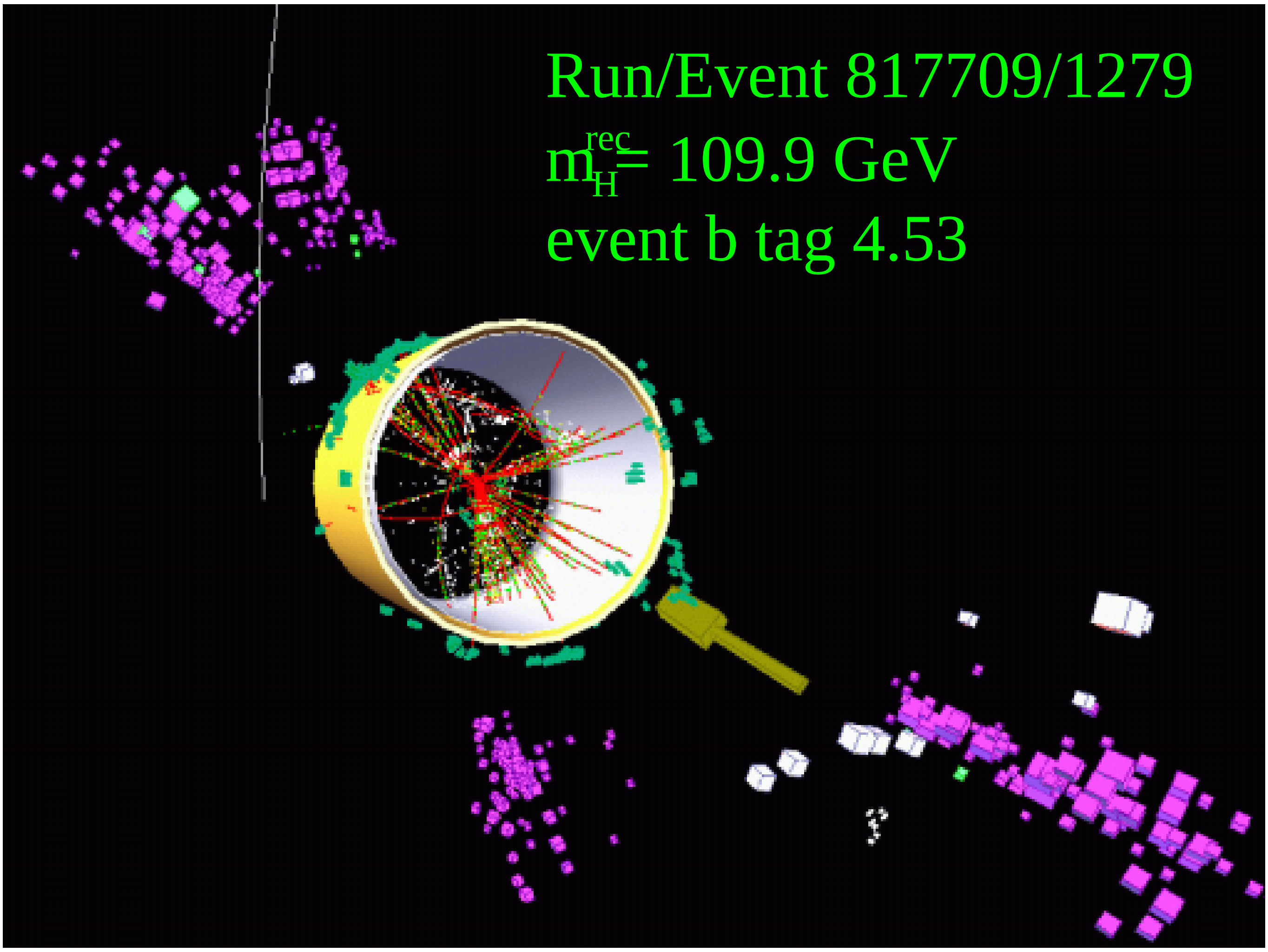
CL_{obs}= 35.22% CL_{bkg}= 54.47% CL_{ave}= 32.73% CL_{med}= 33.83%



Background	83.54
Data	92
Signal	1.63

No significant excess observed

Most significant candidate for $m_h^{\mathrm{hyp}} = 114\mathrm{GeV}$:



How to calculate confidence levels

- Goal of the analysis: Assess the presence or absence of a signal
- From the final variable distributions, an estimator is calculated which is high for background-like experiments and low for signal+background-like experiments
- Most commonly used estimator:

$$\boxed{-2\ln\frac{\mathcal{L}(x|s+b)}{\mathcal{L}(x|b)} = -2\ln Q}$$

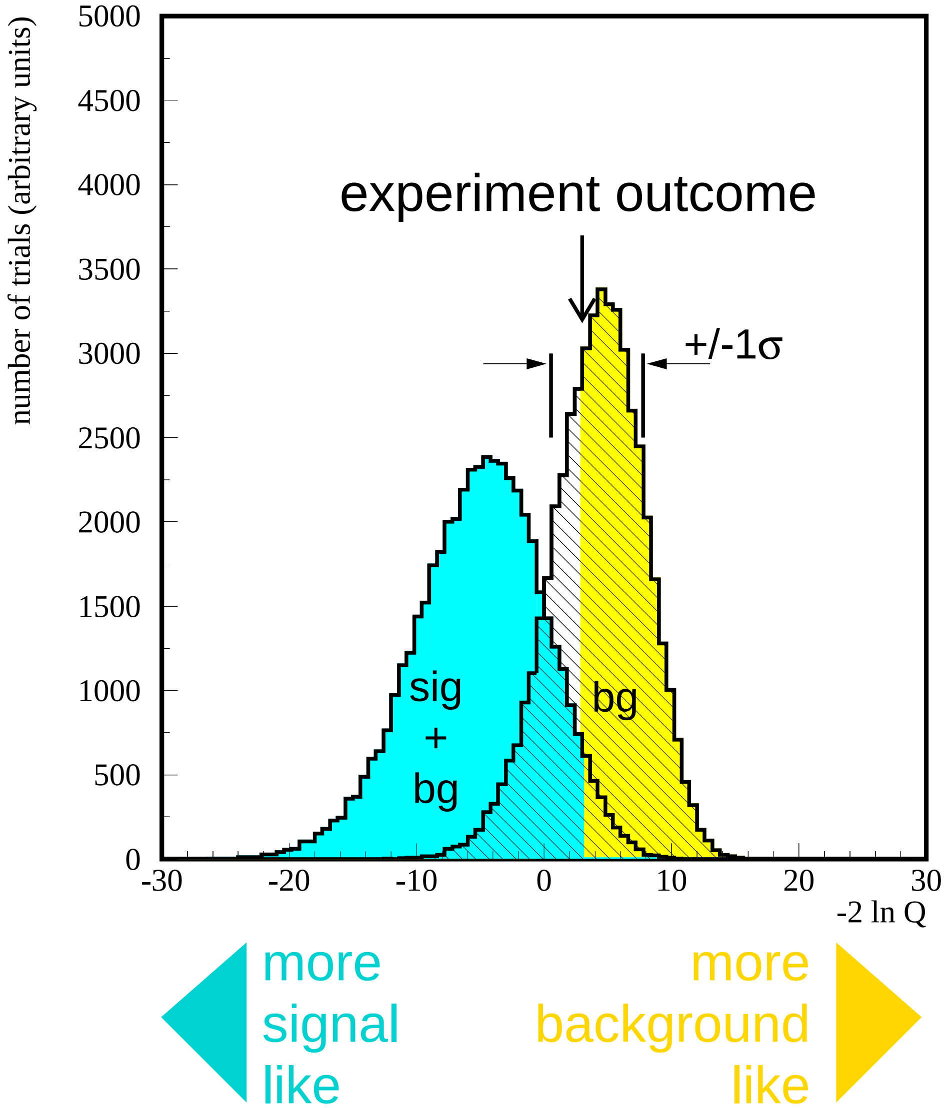
  where

$$\boxed{\begin{aligned}\mathcal{L}(x|b) &= \text{Likelihood of } x \text{ under the hypothesis } b\\ &= \text{product of Poisson probabilities}\end{aligned}}$$

- x can be:
  - data
  - background
  - signal + background

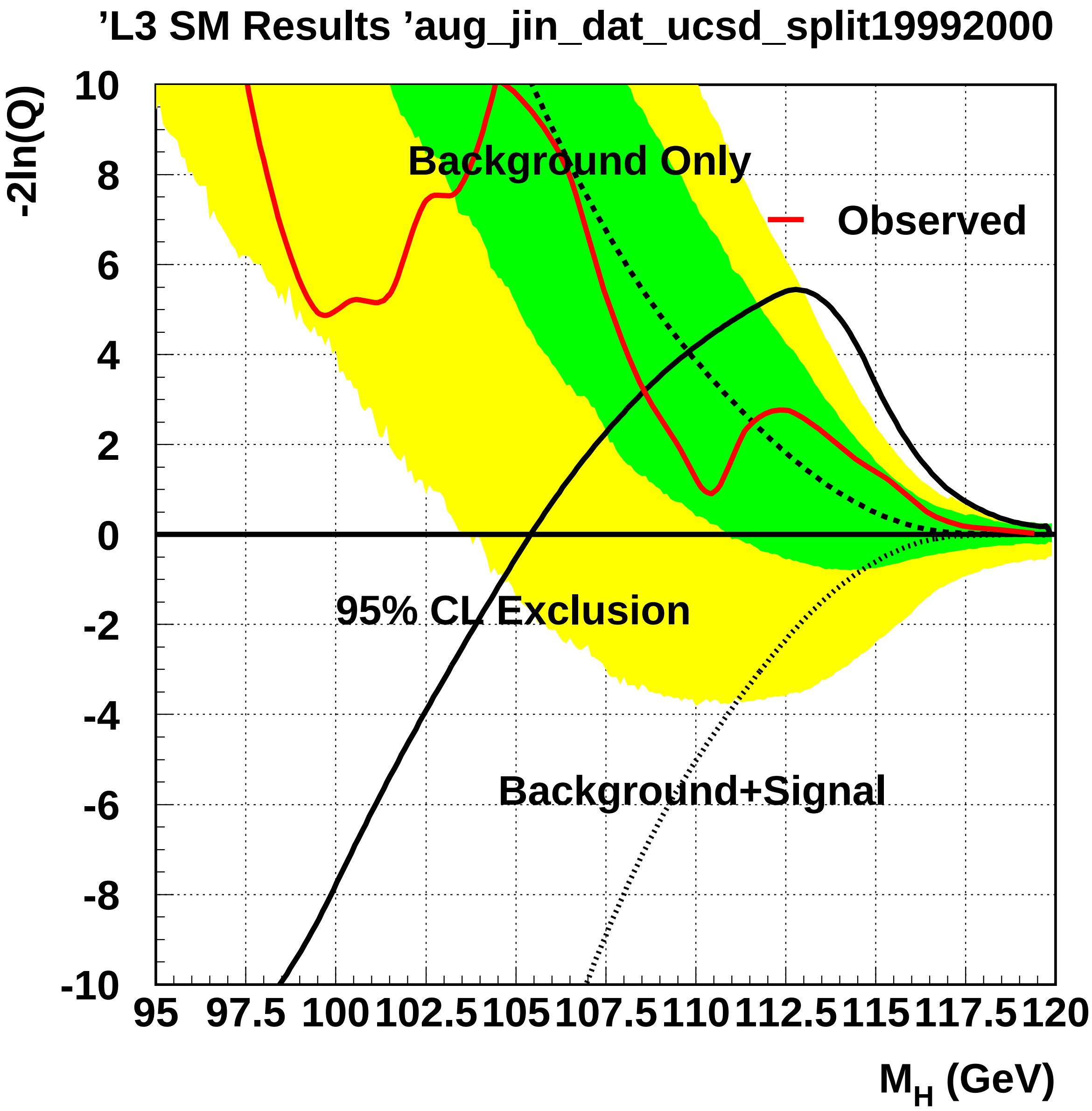
From the expected signal and background distributions, several thousand outcomes are thrown to get the spectra of the background and signal + background estimators.

Example of background and signal + background estimator spectra:



Preliminary L3 results (all channels combined)

$-2\ln Q$ as function of the Higgs mass of the combined L3 results (145 pb^{-1})



How to calculate confidence levels

Given the value of $-2\ln Q$ observed in the data, one calculates:

- CL_b^{obs} = fraction of background trials which are more background-like than the data
- CL_{s+b}^{obs} = fraction of signal + background trials which are more background-like than the data.
- CL^{obs} = 1 - $CL_{s+b}^{obs}/CL_b^{obs}$

The signal is excluded for masses m_H where

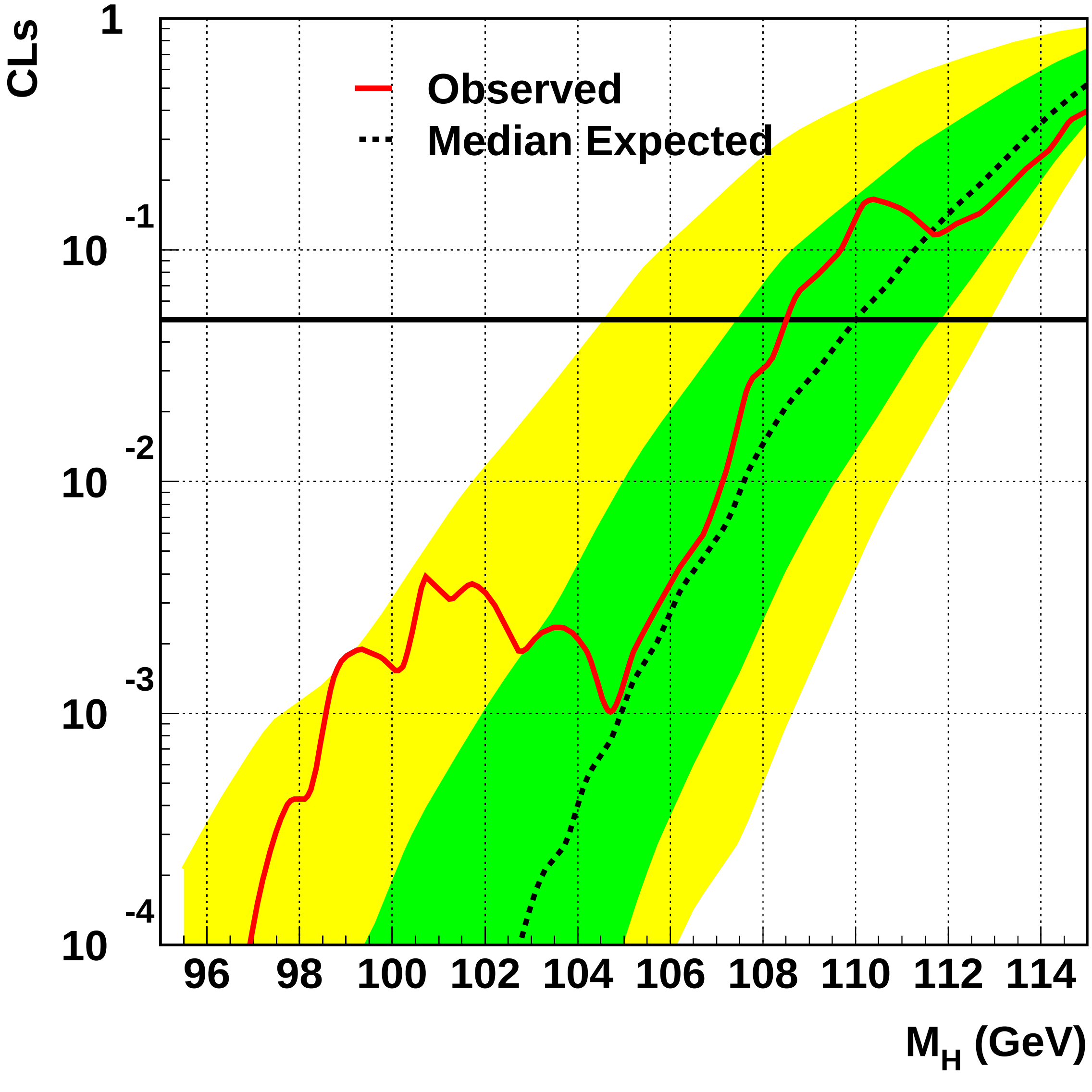
$$CL^{obs}(m_h) > 95\%$$

Advantage of this (frequentistic) method: Systematic errors can be included easily by varying the signal and background cross sections during the trial experiments

Confidence levels can also be computed from the background expectation → expected limit

Preliminary L3 results (all channels combined)

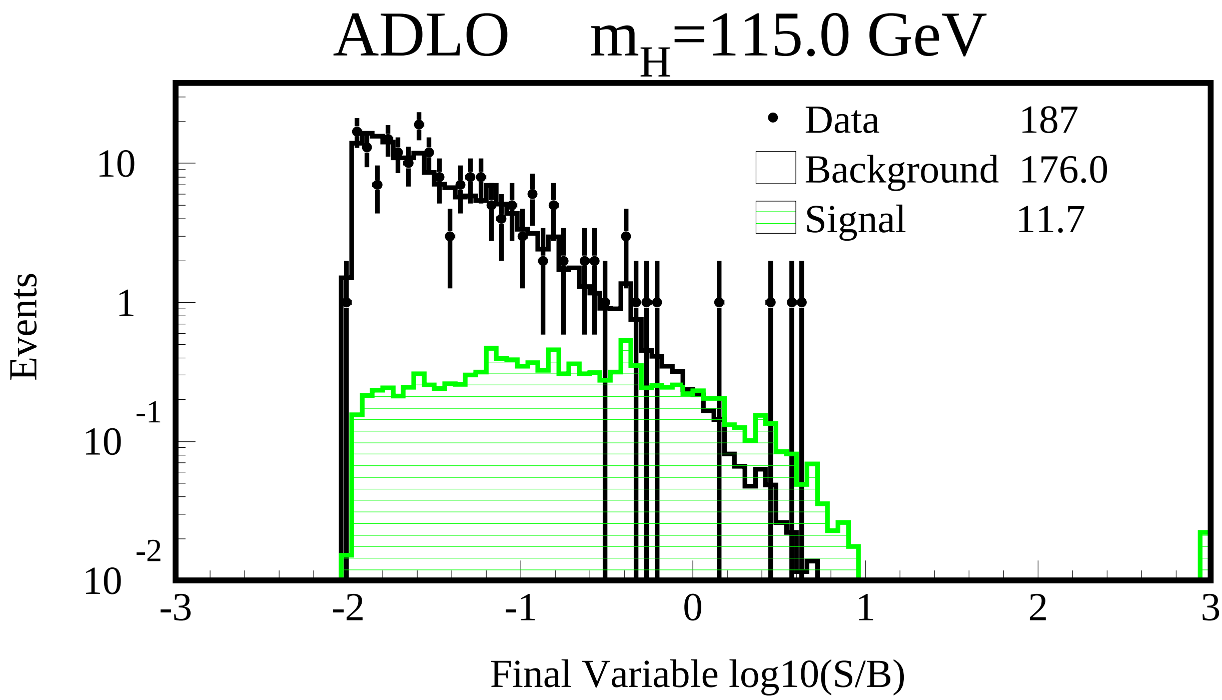
Confidence level as function of the Higgs mass of the combined L3 results (145 pb^{-1})

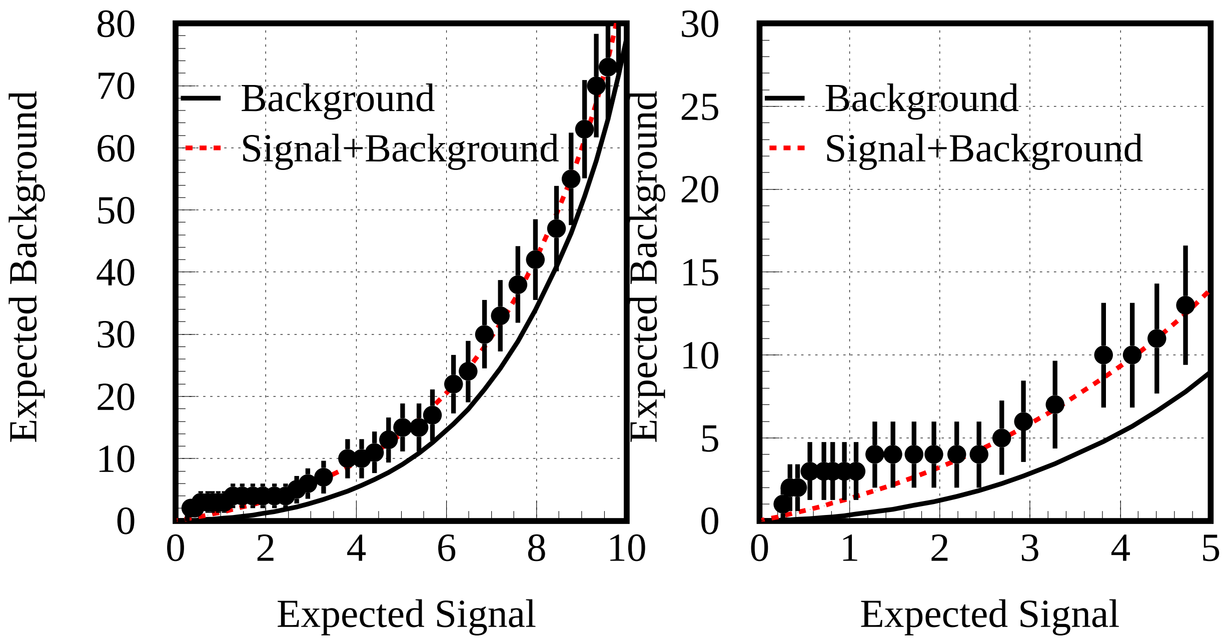


Combined LEP results

About 150pb^{-1} per Experiment

Final variable distribution for all four LEP experiments combined

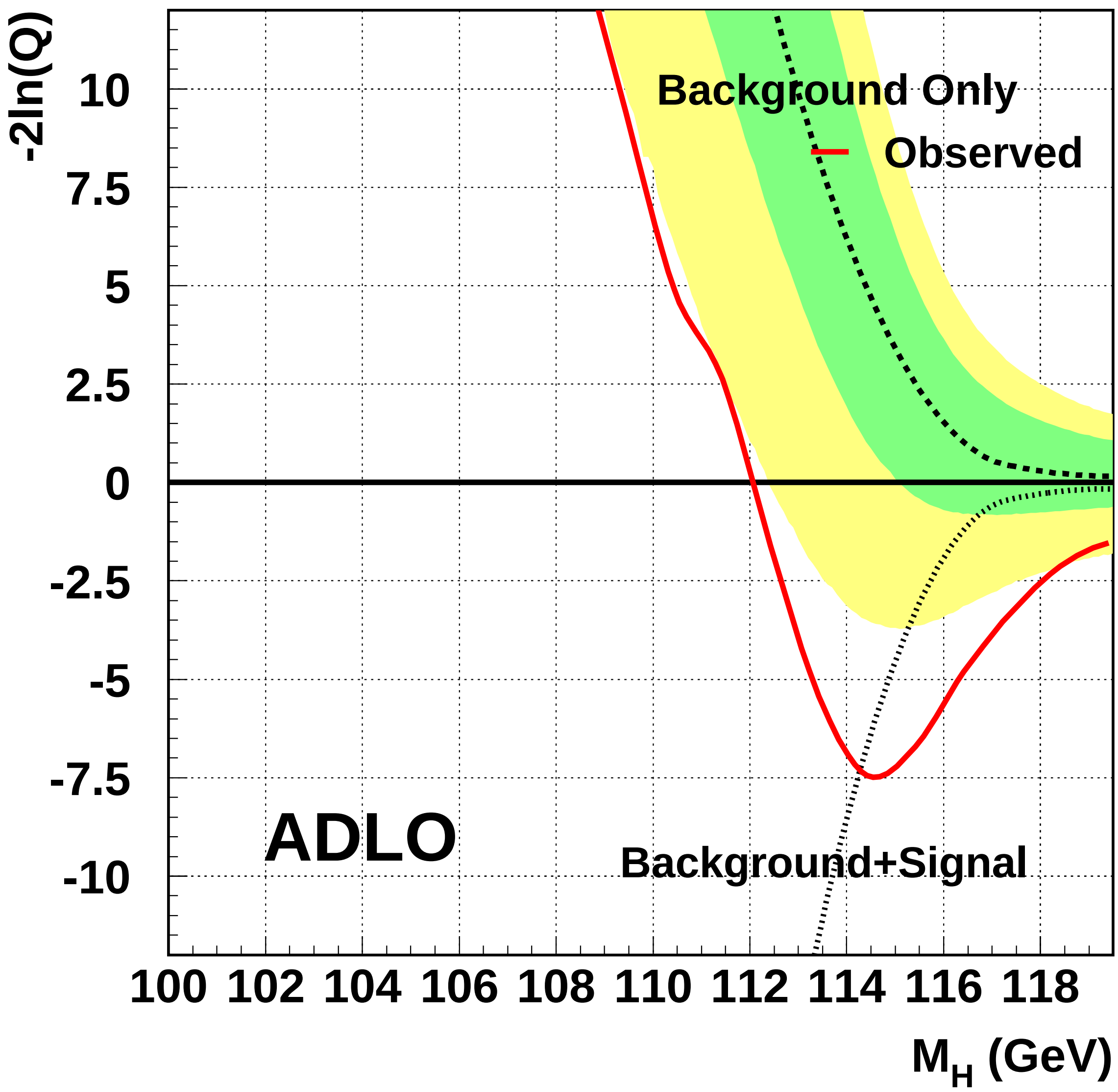




Several highly significant candidates !

Combined LEP results

Log Likelihood ratio curve for the combined result as function of the Higgs mass hypothesis:



Significance of excess at 115 GeV: **3.4 σ**

Summary

- **$170pb^{-1}$ were collected and analyzed in L3 up to now in the Year 2000**
- **Combining all four LEP experiments, 3.4 σ excess is observed around $m_H = 115$ GeV.**
- **LEP got a one month's extension until beginning of November to confirm or disprove this excess**
- **All results are very preliminary. Final calibrations at the end of the run are needed.**