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LEP Higgs results in BSM tests via RooStats

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Outline

- Combined searches at LEP
- Project to publish LEP SM H search in RootStats workspace(s)
- Status of the work

Before LEP combining searches not obvious

- PDG has long experience combining measurements from different experiments: error-weighted averages
 - Maximum likelihood $\rightarrow \chi^2$ minimization
- After first year of LEP, huge "particle obituaries", separate for each experiment
 - Not obvious how to combine exclusion limits
 - E.g. "mass of X particle $> y$ at 95% CL"
 - Special interest in SM Higgs x 4 experiments

Combined LEP Higgs searches

- Standard Model
- MSSM h,H,A
 - Various benchmark and other scenarios
- Charged Higgs (w/o MSSM constraint)
- Invisible Higgs (missing p,E)
- Fermiophobic Higgs (diphoton final state)
- Flavor-independent Higgs search (e.g. 2HDM's with suppressed $H \rightarrow b\bar{b}$)
- See
<http://lephiggs.web.cern.ch/LEPHIGGS/www/Welcome.html>

How were the combinations done?

- Focus on simplest case, SM Higgs
 - We "know" everything except its mass and whether it exists
- Maximum likelihood->likelihood ratio
 - $Q=L(S+B)/L(B)$
 - S symbolizes signal, e.g. SM Higgs
 - For SM Higgs, m_H is parameter of interest
 - For e.g. a constrained MSSM m_A , $\tan\beta$ (others enter rad. Cor., including top mass)
 - B symbolizes background, e.g. Rest of SM, cosmics, ...

The likelihood function

$$\mathcal{L}(\eta) = \prod_{k=1}^N \frac{\exp[-(\eta s_k(m_H) + b_k)] (\eta s_k(m_H) + b_k)^{n_k}}{n_k!} \times \prod_{j=1}^{n_k} \frac{\eta s_k(m_H) S_k(\vec{x}_{jk}; m_H) + b_k B_k(\vec{x}_{jk})}{\eta s_k(m_H) + b_k}$$

- $\eta=1$: Background + e.g. Higgs
- $\eta=0$: Background only

$$-2 \ln Q(m_H) = 2 \sum_{k=1}^N \left[s_k(m_H) - \sum_{j=1}^{n_k} \ln \left(1 + \frac{s_k(m_H) S_k(\vec{x}_{jk}; m_H)}{b_k B_k(\vec{x}_{jk})} \right) \right]$$

LEP Data model for SM Higgs

- Separate search channels
 - 4 experiments
 - ~ 12 sqrt(s)'s from ~ 90 -210 GeV
 - $O(10)$ search channels per experiment
 - Combined likelihood $L = \prod L_i$
 - Takes optimal advantage of different S/B ratios in different channels
- This is standard procedure now

LEP Data Model II

- Channel types
 - "Cut and count": n events observed, b background events expected, $s(mH)$ hypothetical signal
 - Events marked with invariant mass measurement
 - Events marked with inv. mass and a discriminating variable (e.g. NN for bb-tag)
- pdf's (probability distribution functions) expressed either as histograms or functions
 - Background shapes
 - Signal shapes

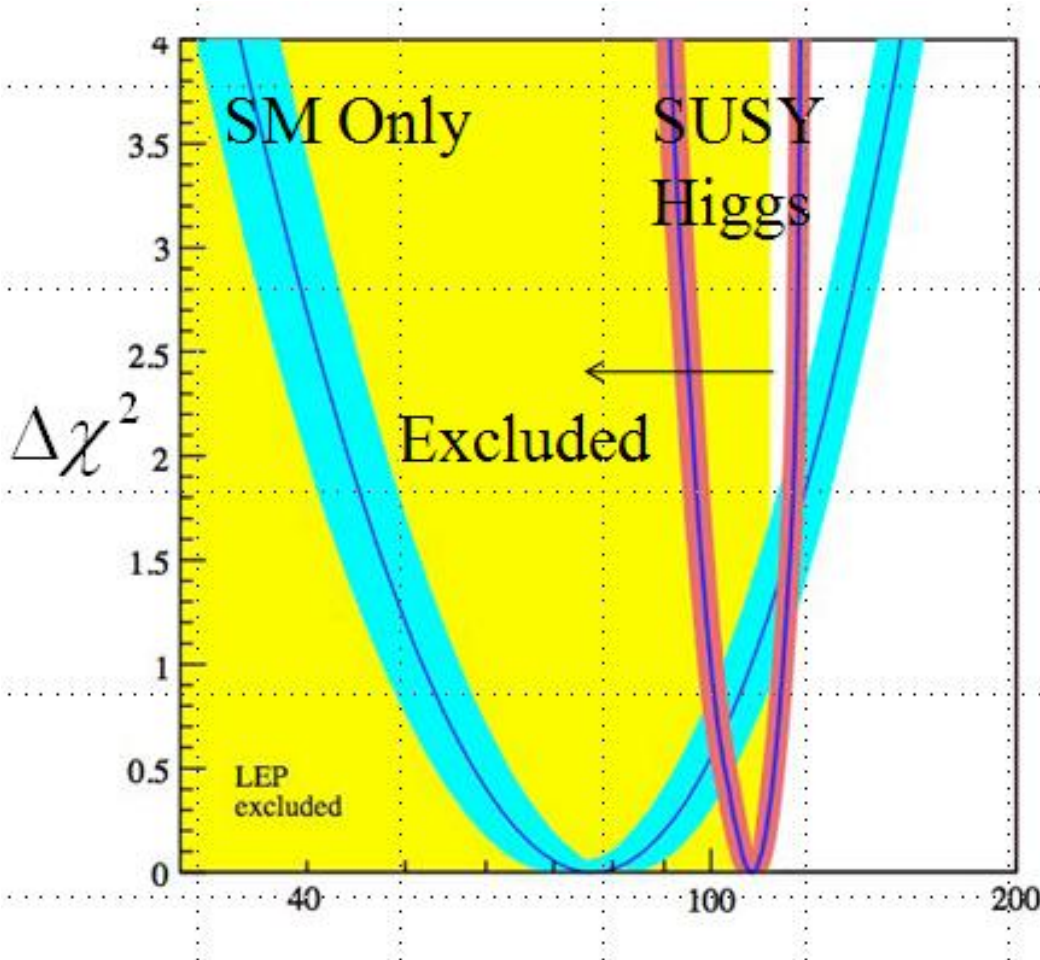
Combining the LEP Data Models

- Every experiment had its own format ☹
 - Eventually had common solution for theory part of the models (cross-sections, widths and branching fractions given model parameters), e.g. MSSM databases for the various scenarios
- Custom top-layer of code to read in the 4 formats and produce L (and derive limits)
 - Each experiment provided straightforward (but slightly different) interfaces to their inputs

Various complications

- pdf of Q (needed for limit extraction) not known from first principles (not high stats)
 - No standard tool, 5 different codes
- Uncertainties treatment
 - Used normal distribution, not always a good description
 - Hybrid frequentist/Bayesian procedure
- Correlated uncertainties (treated correctly)
- Limit-setting a CPU-consuming affair

Combining direct and indirect "searches"



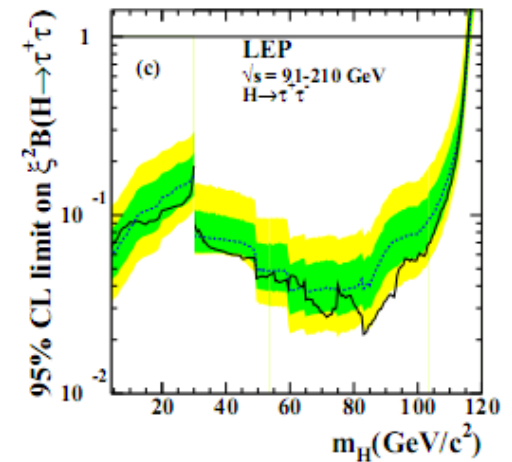
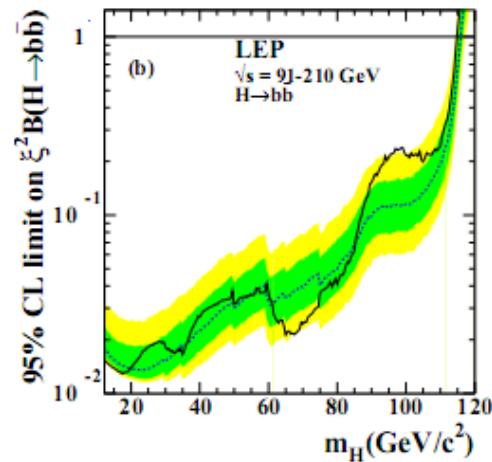
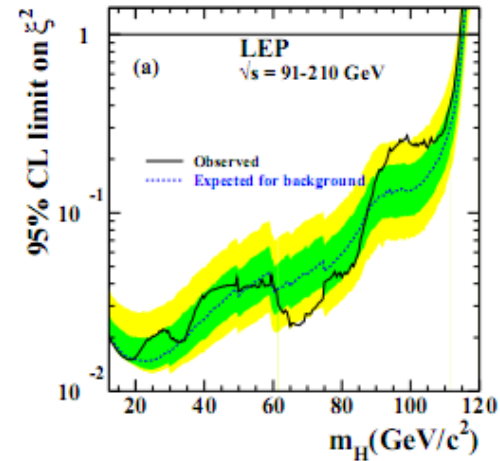
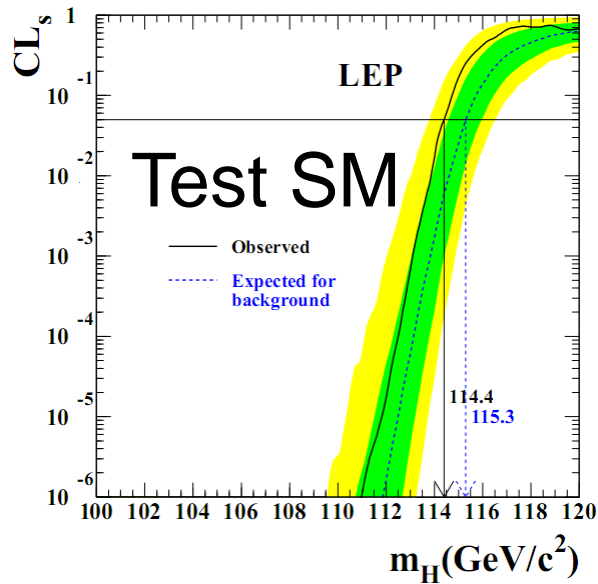
- Should NOT convert exclusion confidence to probability to χ^2
- Combine likelihoods
- Without direct evidence we don't know what the minimum means.

The Vision

- To re-publish the experimental results in a format that allows anybody to reproduce the standard results and to test alternate theory models against the data
- To enable arbitrary (but relevant!) combinations of published search results
 - E.g. LEP+Tevatron+LHC results for SM Higgs in region $m_H \sim 115$ GeV
 - And not only limits; significance of observations and parameter estimation as well

First steps BSM

Vary HVV couplings



HiggsBounds for limit-setting

- Leverages 83 (!) published bounds on cross-section ratios
 - LEP and Tevatron neutral (CP even and odd) and charged Higgs searches
- Model tests
 - Number of neutral and charged Higgs
 - Total decay widths
 - Branching fractions
 - Production cross-sections
- Limitations
 - Only uses most sensitive search of the 83
 - Gives only y/n answer to question of 95% CL exclusion
 - Not useful for limit->discovery->measurement
- References: arXiv:0811.4169 [hep-ph], arXiv:1012.5170 [hep-ph] (Bechtle, Brein, Heinemeyer, Weiglein, Williams)

The Project (first phase)

- Get the LEP Higgs search results into RooStats workspaces and publish these
 - What this (RSW) actually means (!) by Kyle Cranmer in later talk
- Philip Bechtle, Kyle Cranmer, Tom Junk, Alex Read, a (PB) postdoc from May
- Goal is to have results for SM H for the summer

Plan

- Get the SM code running
- Reproduce published results
- Build code for transport of data models and observations to RooStats workspace(s)
- Reproduce published results
- Publish the workspace(s)
- Publish documentation and template for BSM test
 - Ex: Compare with HiggsBounds results for radion limits in Randall-Sundrum (RS) model

Status

- Philip has MSSM code compiling and running on SLC4 platform
- Alex has ~80% of SM H code compiling and linking on SLC5
 - gcc 2-> gcc4
 - g77->gfortran
 - (will try 64-bits when 32 version checks out)
 - Depends mainly on CERNLIB, but a little root and NAGLIB as well

Summary

- Many combined Higgs searches at LEP and Tevatron published – and very soon LHC
- HiggsBounds gives simplified approximate approach to setting bounds on new models which affect Higgs production and decay
- RooStats workspace proposed as HEP results publication format
 - Work has started to transfer LEP SM Higgs to RooStats
 - Will allow flexible tests of BSM's in Higgs sector against all relevant direct searches
 - And maybe, just maybe, we can go beyond exclusion 😊