A Generic Fitter Project for HEP Model Testing

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- **The standard electroweak precision fit**
- **Constraining the 2HDM parameter space**

Flavour as a Window to New Physics at the LHC (June 10th, 2008)

The Gfitter Project

- Gfitter - A Generic Fitter Project for HEP Model Testing
  http://cern.ch/Gfitter

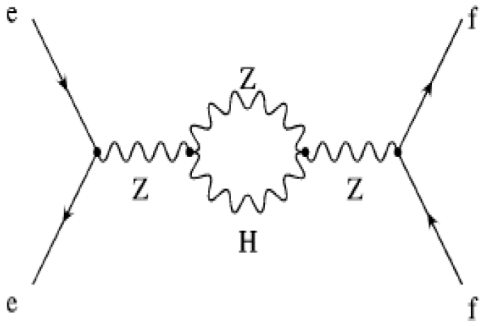
- Written in C++ and built upon ROOT
- Organized in one core statistic/fitting package, and physics plugin packages
  - SM, Two Higgs Doublet, SUSY, etc.
- Dynamic parameter caching => fast
  - Only Recalculation of parameters when needed
- Based on frequentist analysis
  - CL by toy-analysis
  - Goodness of fit by toy-analysis
- Transparent fitting and steering card interpretation
  - Usage of XML format
- User-friendly and flexible tool

Global fit of the Electroweak Standard Model

Comparison of electroweak precision observables with SM theory

- Idea: Radiative corrections give precise predictions for EW observables
- 7 free parameters:

$$\Delta\alpha^{(5)}_{had}(M_Z^2), \alpha_S(M_Z^2), M_Z, M_H, m_{top} \qquad m_c, m_b$$

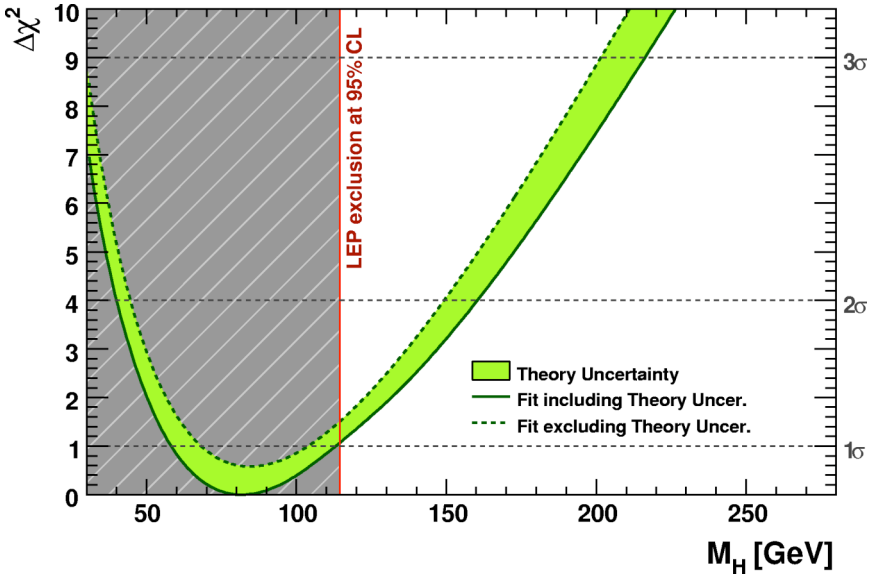


- We use the *on-mass-shell (OMS)* scheme (like Zfitter)
  - Complete two loop corrections incl. the known higher order QCD and QED for most of the observables
- Currently most precise calculations
  - NNNLO corrections for hadronic Z decays [Baikov,Chetyrkin,Kühn]
  - Complete two-loop plus known three-loop corrections for M_W and $\sin^2\Theta_{eff}$ [Awramik, et al.]

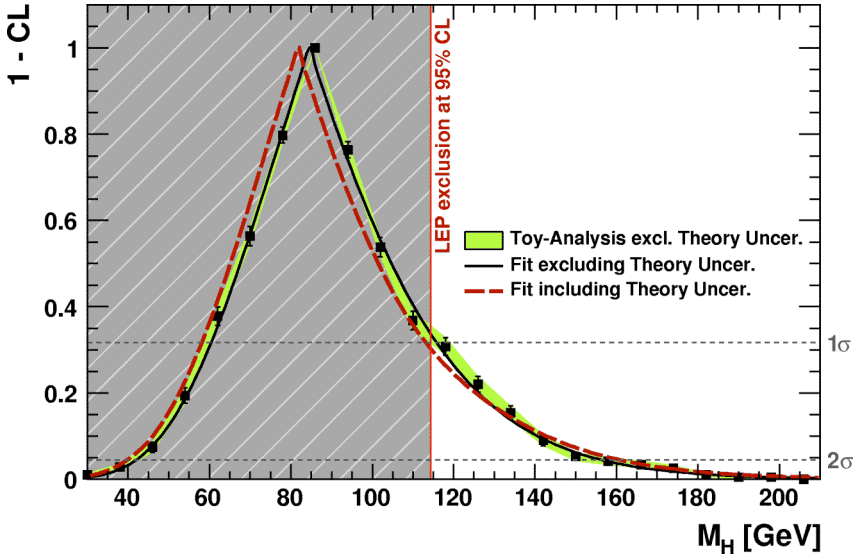
- 21 free parameters in the SM Lagrangian can be reduced to 5 (7) floating fit parameters:
  - photon mass and neutrino masses = 0
  - charged leptons and light quark masses are small compared to M_Z and/or precisely measured
    - Hardly any influence on the fit result
  - M_W and M_Z are coupled via the weak coupling constant G_F
    - M_W can be computed
  - G_F is one of the most precise measurements in physics
    - G_F is treated as constant

Prediction of the Higgs Mass

Without direct Higgs Searches



Verified with toy analysis



$$\chi^2_{\min} = 16.4$$

$$M_H = 82^{+31}_{-24}\ GeV \qquad M_H < 160\ GeV\ at\ 95\%\ CL$$

Treatment of theo. Uncertainties: mainly $M_W \pm \Delta M_W(theo)$ $\sin^2\Theta^{lept}_{eff} \pm \Delta\sin^2\Theta^{lept}_{eff}(theo)$

New Treatment: (à la Rfit [CKMFITTER])

If measurement

- within theory uncertainty: **no contribution** to χ^2.
- outside theory uncertainty: χ^2 determined by **distance** between **measurement** and **prediction ± uncertainty**

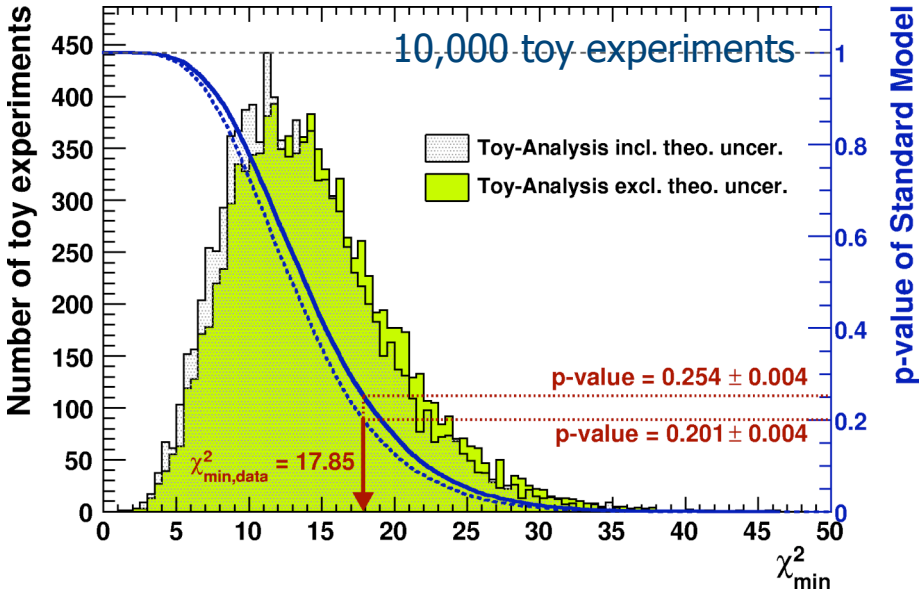
Old Treatment:

Band was done by **shifting** the predictions by these uncertainties **redoing** the scan and **choosing** the worst cases

Testing the Standard Model

Goodness of global fit
(by using toy analysis)

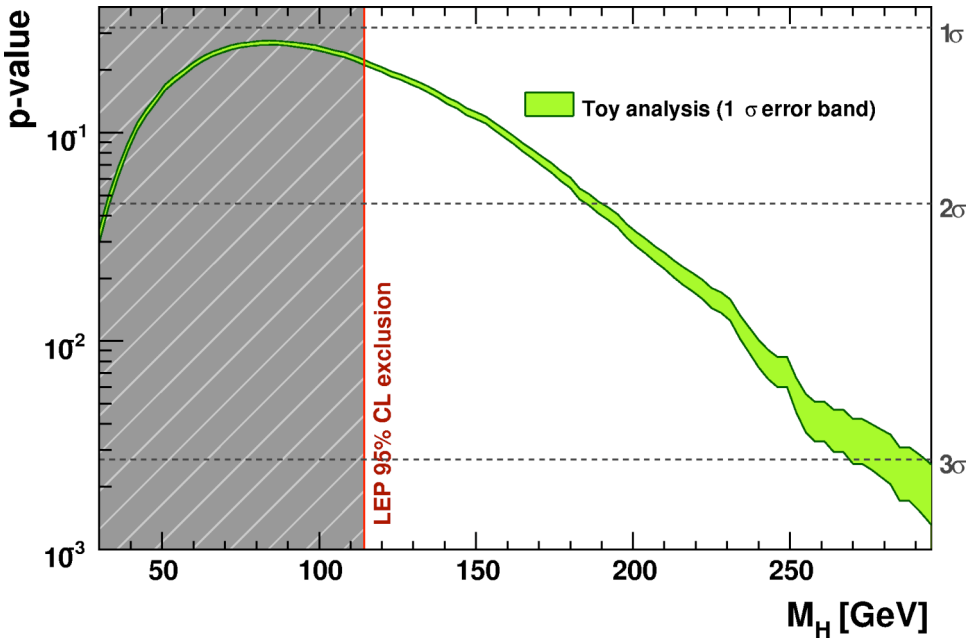
- Generate toy sample by random sampling from Gaussian distributions around initial fit results (Correlations are taken into account)
- Refit with new values for observables, obtain a new χ^2



P-value:

- Probability for wrongly rejecting the SM
- for getting a χ^2 larger than the χ^2 of the fit

p-value for electroweak fit for given Higgs masses
(assuming negligible errors)

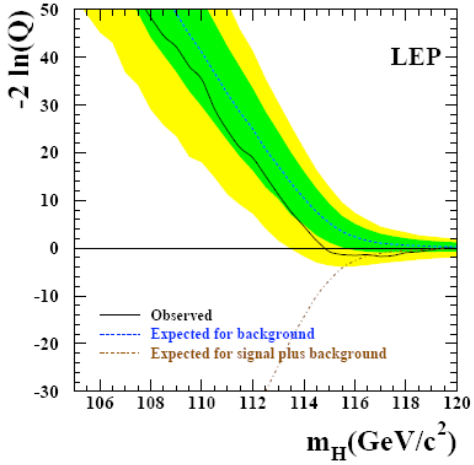


- Compute p-values for fixed Higgs masses using toy experiment method
- Here: p-value is greater than for fit with free Higgs mass
  - Higgs mass fixed
  - n_{dof} increased by one

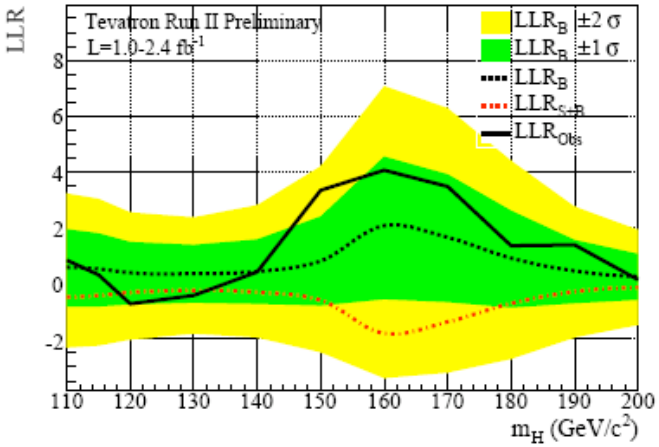
Prediction of the Higgs Mass (II)

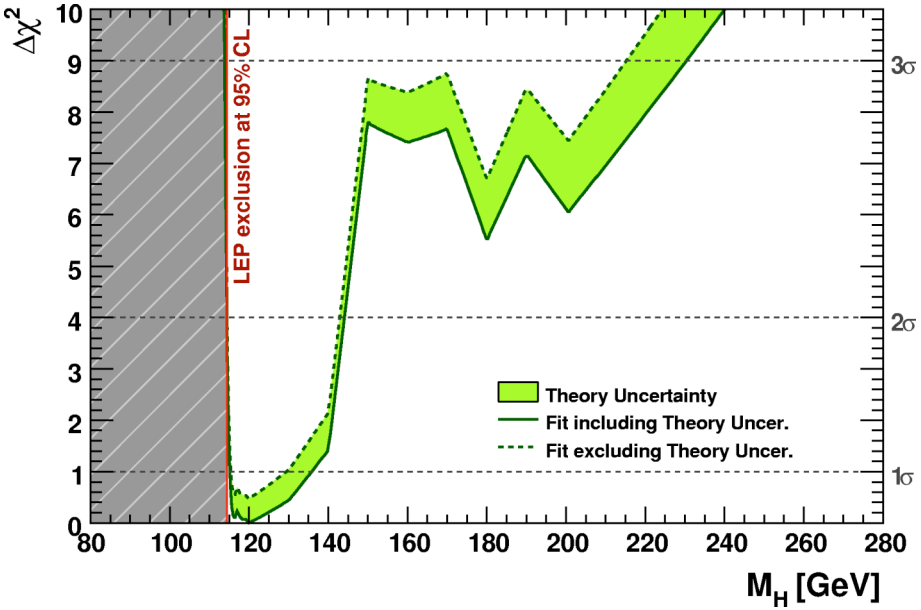
Including constraints from direct Higgs Searches

LEP:



Tevatron:





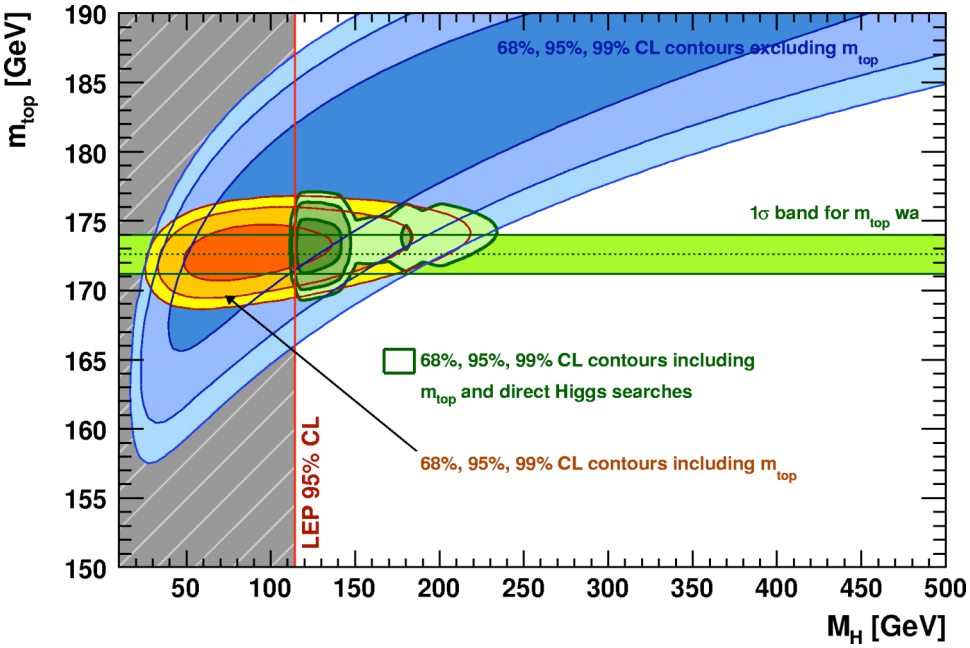
Inclusion of direct searches provides more stringent constraint:

$$\chi^2_{\min} = 17.9$$

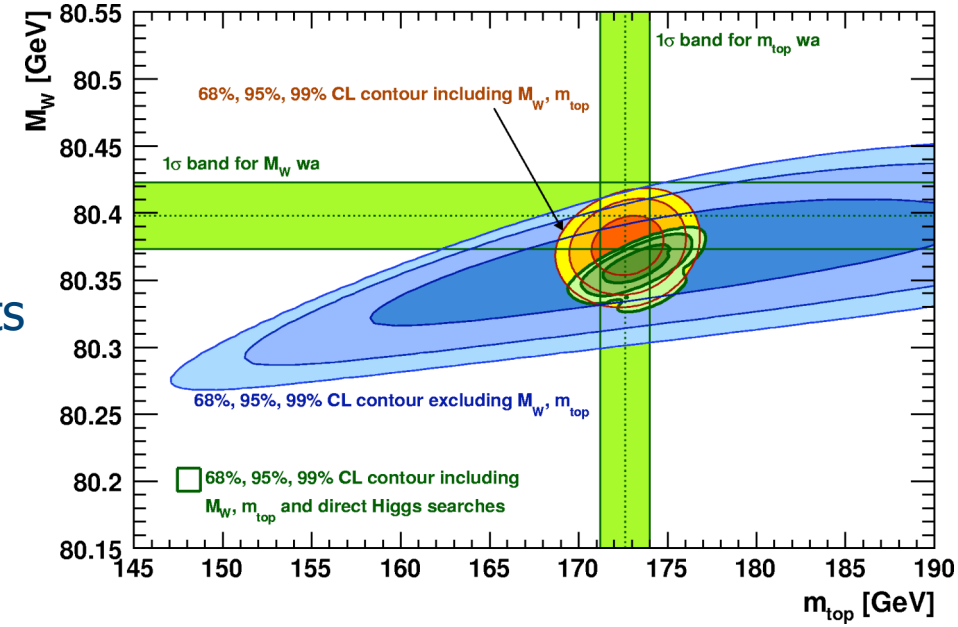
$$M_H = 120^{+16}_{-5} \quad GeV$$

$$M_H < 145 \quad GeV \quad at \quad 95\% \quad CL$$

Two-Dimensional Scans



- When m_{top} measurement removed: allowed band rather big
- Good constraint if m_{top} measurement is included
- Positive correlation value between M_H and m_{top} (blue contours)



- Current values agree with the fit results
- However need more precision on W and top mass measurements
- Good probe of SM, if M_H is measured

Extension beyond Standard Model

- 2HDM (type-II) as a first step
- Add an extra Higgs doublet to SM
  - One doublet couples to the up-type fermions
  - One doublet couples to the down-type fermions

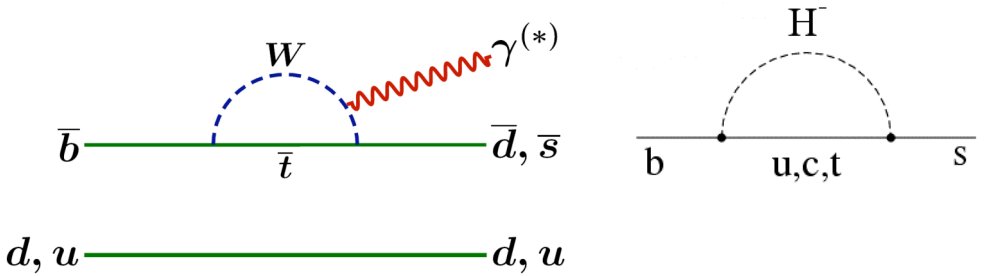
  } type II
- 6 free parameters

$$M_{H^\pm}, M_{A^0}, M_{H^0}, M_h \qquad \tan\beta = \frac{v_1}{v_2}, |\alpha| \le \frac{\pi}{2}$$

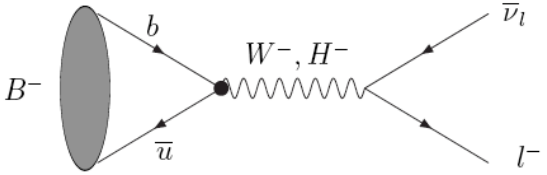
  - α relates mass eigenstates with the field doublet
- So far only looked at processes involving a charged Higgs exchange
  - Sensitivity to M_{H+} and tanβ
- This is work in progress

Sensitive Observables

- Study Observables sensitive to charged Higgs exchange
  - FCNC b → sγ



  - (semi-)leptonic Meson decays
    - B → τυ
    - B → Dτυ
    - K → μν



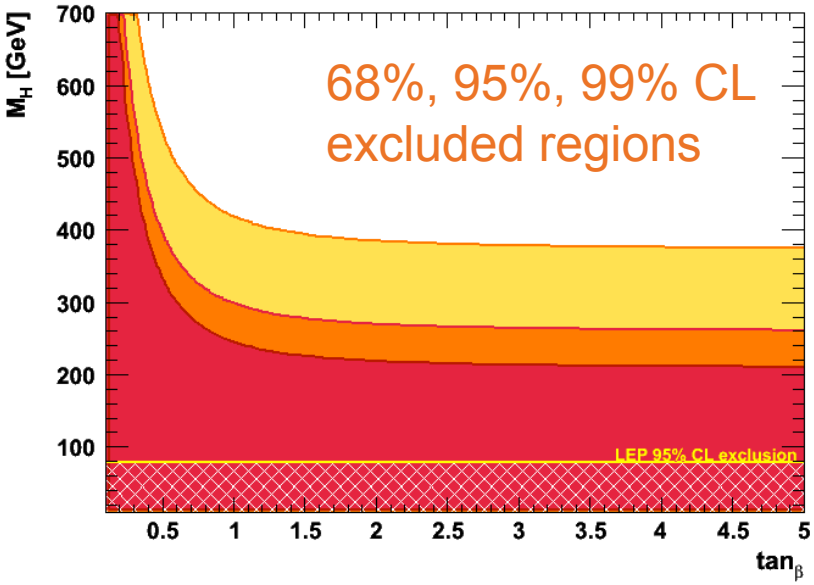
  - Hadronic branching ratio of Z to b-quarks R_b

- Gfitter package provides easy way to propagate all exp. and theo. uncertainties into limits

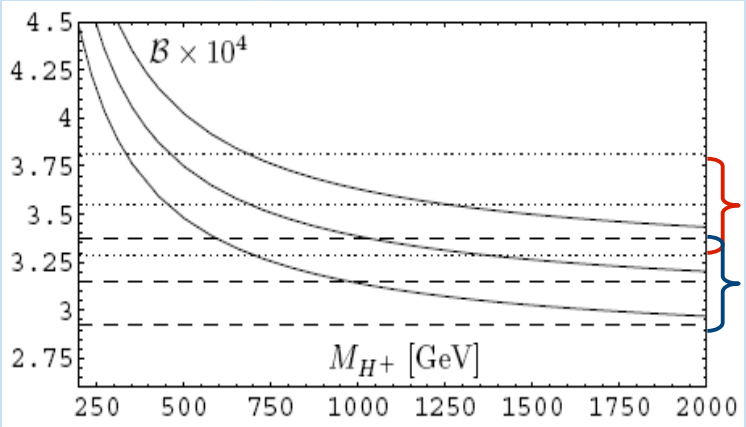
$B \rightarrow X_s \gamma$

Experimental World Average:
$BF(B \rightarrow X_s \gamma) = (3.52 \pm 0.25)\ 10^{-4}$

SM prediction:
$BF(B \rightarrow X_s \gamma) = (3.23 \pm 0.15)\ 10^{-4}$



$BF(B \rightarrow X_s \gamma)$ dependence on M_{H+}



Misiak et. al, Phys.Rev.Lett.98:022002,2007 & Gambino, Misiak, private communication

Branching fraction only sensitive to small tanβ
What is the correct N_{dof}?

Do we only want to set a lower limit on M_H?
(one-sided vs two-sided CL intervals)

B → τυ, B → Dτυ and K→μν

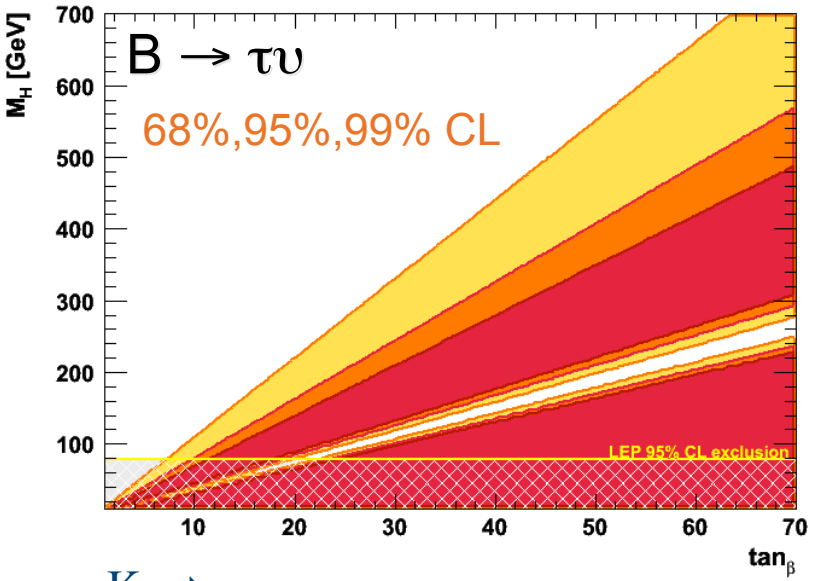
Hou, Phys.Rev.D48:2342-2344,1993

BF(B→lν) dependence on M_{H+} and tanβ:

$$\Gamma(P \to \ell\nu) = \frac{G_F^2}{8\pi} f_P^2 \, m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2 |V_{q_1 q_2}|^2$$

$BR_{2HDM} = BR_{SM} (1- (\tan\beta \, m_B/m_H)^2)^2$

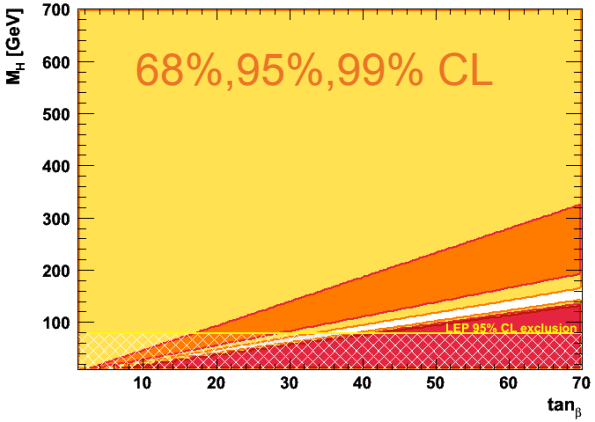
$$BR(B \to \tau\nu) = (1.41 \pm 0.43) \cdot 10^{-4}$$



Similar for B → Dτν

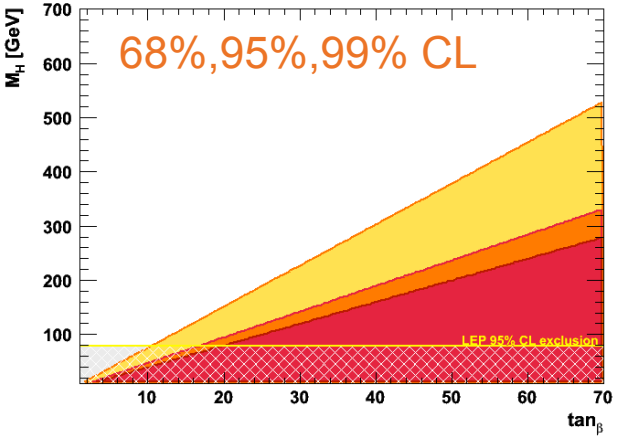
$$\frac{BR(B \to D\tau\nu)}{BR(B \to De\nu)} = 0.416 \pm 0.117_{stat} \pm 0.052_{syst}$$

Kamenik, Mescia 0802.3790[hep-ph]



K → μν

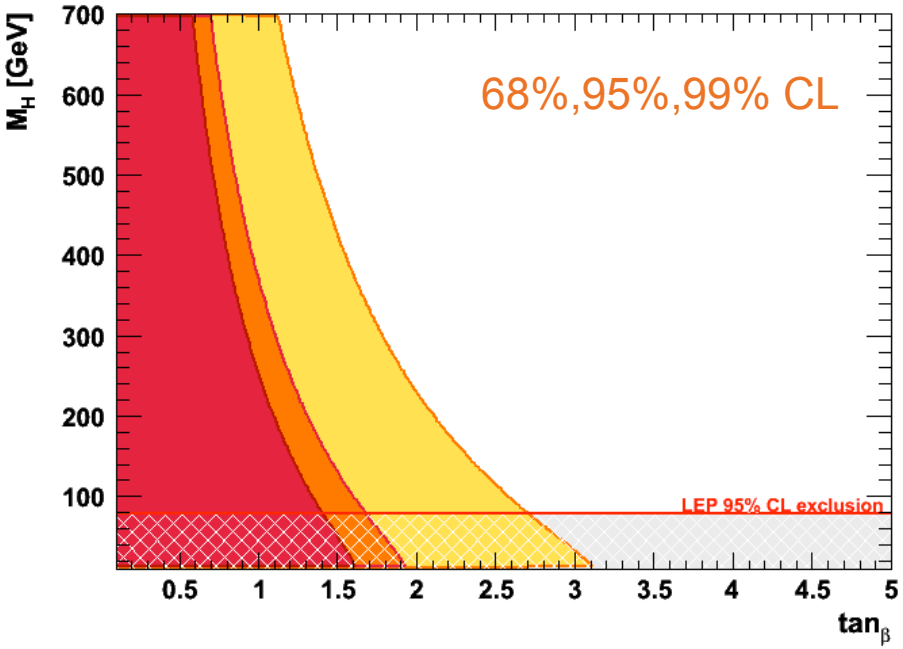
$$\frac{BR(K \to \mu\nu)}{BR(\pi \to \mu\nu)} = 1.004 \pm 0.007$$



FlaviaNet 0801.1817[hep-ph]

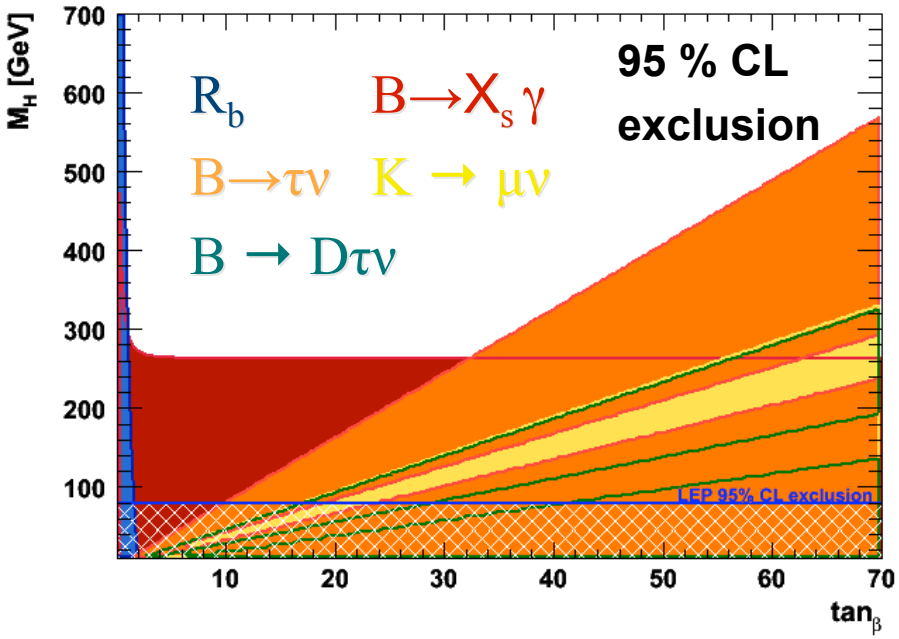
$Z \rightarrow b\bar{b}$

- Higgs exchange modifies left- and right- handed couplings
- We use value for R_b from our SM fit:
  $R_b = 0.21580 \pm 0.00007$
- LEPEWWWG
  $R_b = 0.21629 \pm 0.00066$
- Only sensitive to 2HDM parameter space at low tanβ



The complete picture

Overlay of individual 95% CL excluded regions

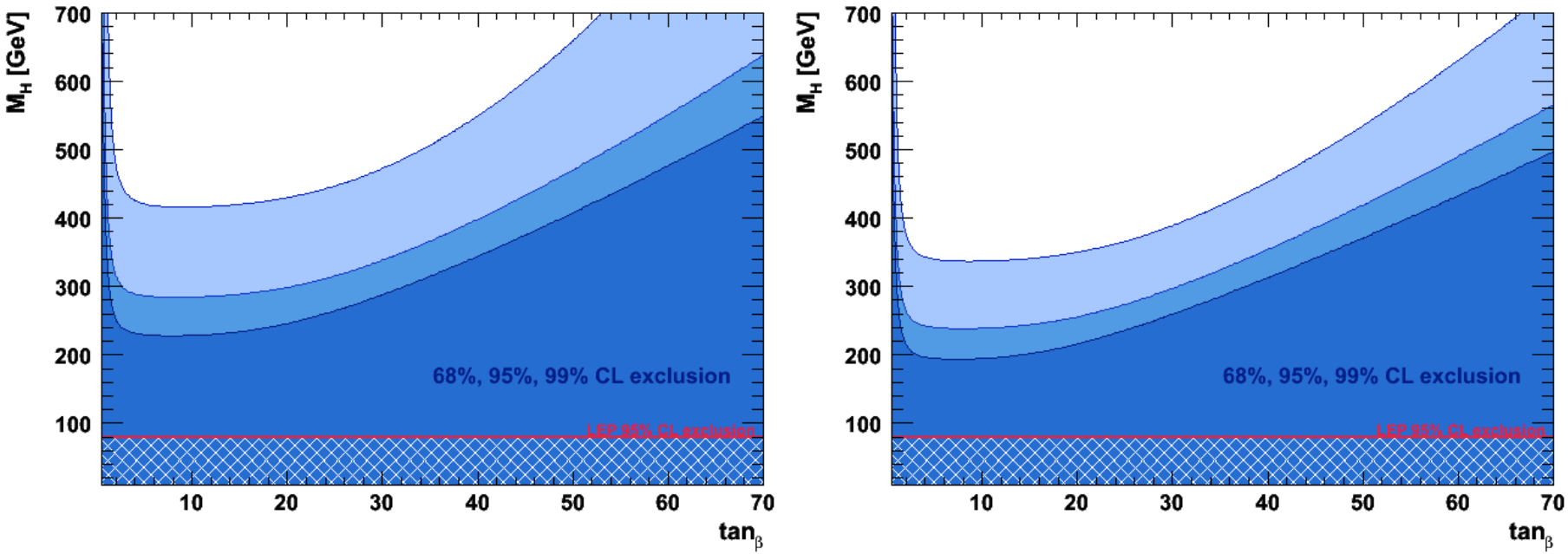


(assuming 1 dof, two-sided limits)

Constraint on 2HDM (type II)

Combining all these measurements in one fit:

(results depend on assumptions made)



assuming 1 dof
(two-sided CL limits)

$\chi^2_{min} = 2.3$
(M_H = 850 GeV
tanβ = 10)

assuming 2 dof
(two-sided CL limits)

The “truth” is probably somewhere in between.

Will perform dedicated toy studies for grid in M_H-tanβ plane to resolve degrees of freedom and one-sided vs two-sided limits

Conclusions

- Gfitter is a generic Fitting Tool for HEP analysis testing
  - user friendly, C++, ROOT based
- The Gfitter SM fit
  - Including direct Higgs searches
  - M_H<145 GeV at 95% CL
  - p-value of SM = 0.254±0.004
- Constraints in 2HDM parameter space
  - Simultaneous fit of several constraints
  - will include statistical interpretation based on toy experiments
- Plan is to extend/interface to more general SUSY models
- Gfitter paper in preparation!

http://www.cern.ch/gfitter