Predictions from Electroweak Precision Measurements

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❶ Introduction

- The gauge sector of electroweak interactions is given by three free parameters e.g. $\alpha, m_{\mathrm{Z}}, G_{\mathrm{F}}$

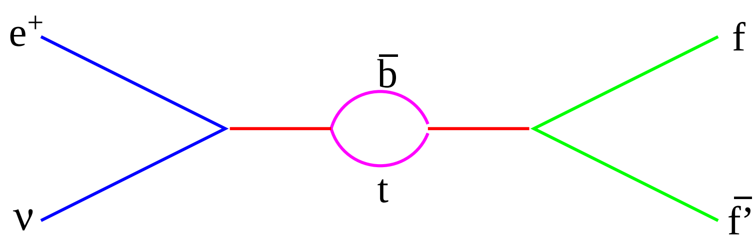
➠ All other observables can be predicted

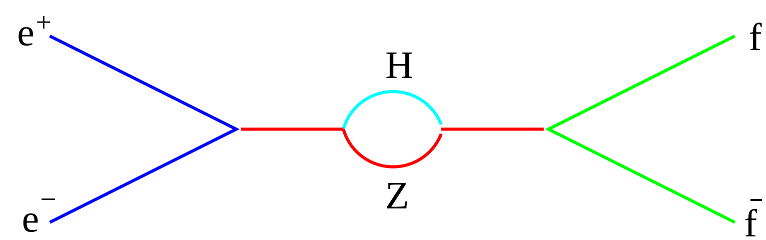
- Expect loop corrections of order $\alpha \sim 1\%$

➠ The ew. precision data are much better than that

- At loop level all other parameters of the model enter

  e.g. m_{t} m_{H}





➠ Can use precision data to constrain unknown model parameters

Structure of the radiative corrections

- The three most precise measurements are used to fix the model $(\alpha, m_{\rm Z}, G_{\rm F})$
- The high energy data are then basically given by three more quantities
  - The partial widths of the lepton ($\Gamma_{\rm ff}$) give the total coupling strength of the Z so fermions (LEP (+ILC))
  - The asymmetries on the Z give the ratio of the Z vector to axial vector coupling (LEP, SLD (+ILC))
  - The W-mass is sensitive the the W-f couplings (LEP + Tevatron (+LHC, ILC))
  - In addition the top mass is needed because of its large loop effects (Tevatron (+ LHC, ILC))

  (the difference between different fermions has little sensitivity to new physics)
- Some low energy parameters (g-2, $b \to s\gamma$) have additional sensitivity to models like SUSY

Parameterisation of radiative corrections:

$$g_{Af} \rightarrow \sqrt{1+\Delta\rho_f}\, g_{Af}$$
$$\frac{g_{Vf}}{g_{Af}} = 1 - 4|Q_f| \sin^2\theta^f_{eff}$$
$$m_W^2 = \frac{1}{2} m_Z^2 \left(1 + \sqrt{1 - \frac{4\pi\alpha}{\sqrt{2} G_F m_Z^2} \frac{1}{1-\Delta r}} \right)$$

Parameter transformation:

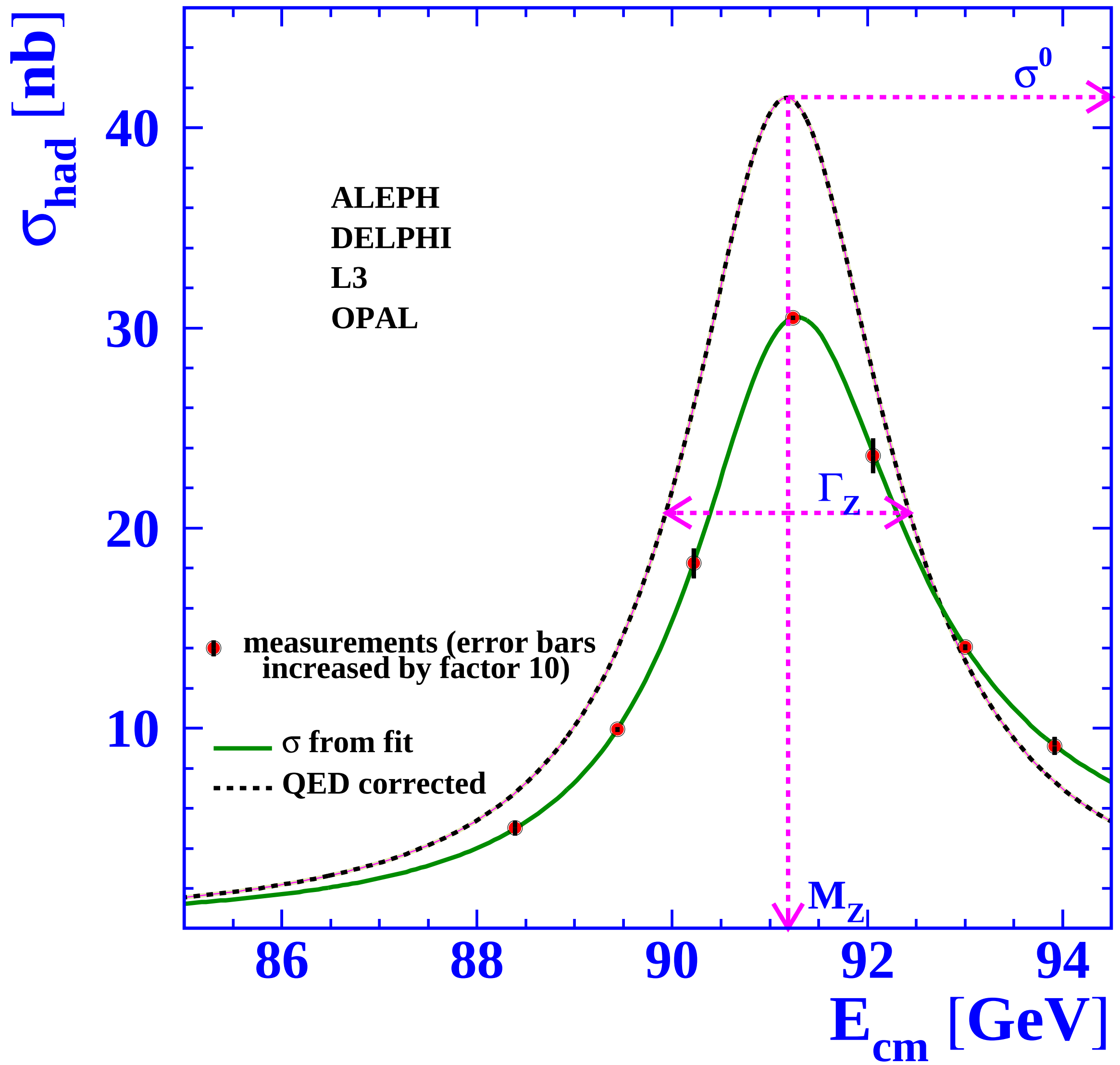
$$\Delta\rho_\ell = \varepsilon_1$$
$$\sin^2\theta^l_{eff} = \frac{1}{2}\left(1 - \sqrt{1 - \frac{4\pi\alpha_{QED}(m_Z^2)}{\sqrt{2} G_F m_Z^2}} \right) \times (1 - 1.43\varepsilon_1 + 1.86\varepsilon_3)$$
$$\frac{1}{1-\Delta r} = 1 + 1.43\varepsilon_1 - \varepsilon_2 - 0.86\varepsilon_3$$

Or alternatively:

$$S = \frac{4\sin^2\theta}{\alpha}(\varepsilon_3 - \varepsilon_3(\mathrm{SM}))$$
$$T = \frac{1}{\alpha}(\varepsilon_1 - \varepsilon_1(\mathrm{SM}))$$
$$U = \frac{-4\sin^2\theta}{\alpha}(\varepsilon_2 - \varepsilon_2(\mathrm{SM}))$$

❷ The Data

Z-lineshape

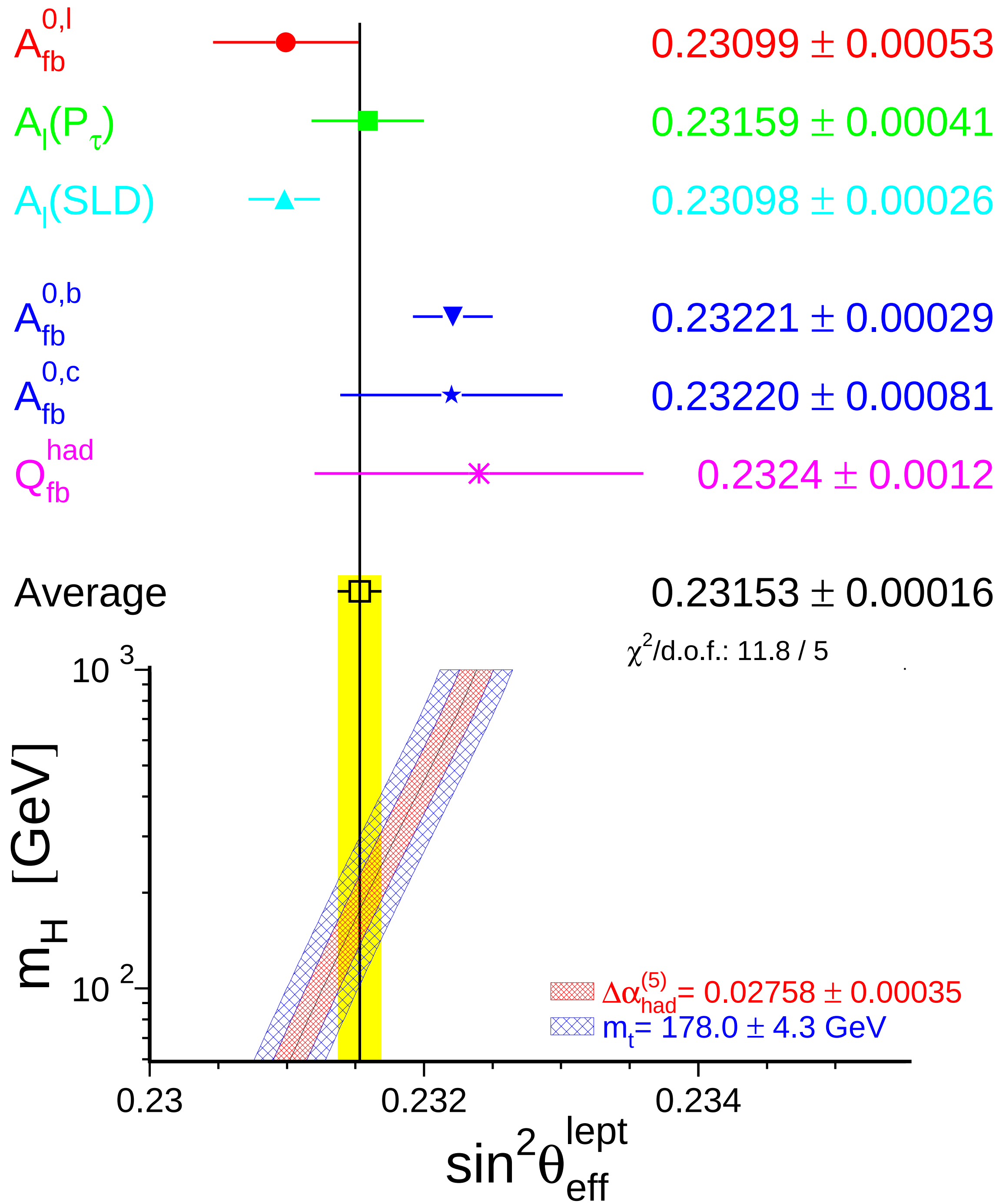


- Energy dependent cross section for leptons and hadrons

➠ m_Z, Γ_Z, Γ_ℓ, Γ_{had}

Z asymmetries

- Several asymmetries on the Z: A^{ℓ}_{FB}, $A^{\mathrm{b}}_{\mathrm{FB}}$, A_{LR}, $\mathcal{P}_{\tau}$...
- All sensitive to $\sin^2\theta^l_{eff}$
- Most precise ($A^{\mathrm{b}}_{\mathrm{FB}}$, A_{LR}) differ by about 3σ
- No explanation for this if new physics only in loops



W-mass

- Sensitive to W-couplings in conjunction with G_{F}
- LEP: Direct reconstruction mainly from semileptonic channel (statistics limited)
- Tevatron: transverse mass, systematics limited by Z-statistics

top-mass

- Enters only in loops
- However large effects due to quadratic dependence
- Few GeV precision needed

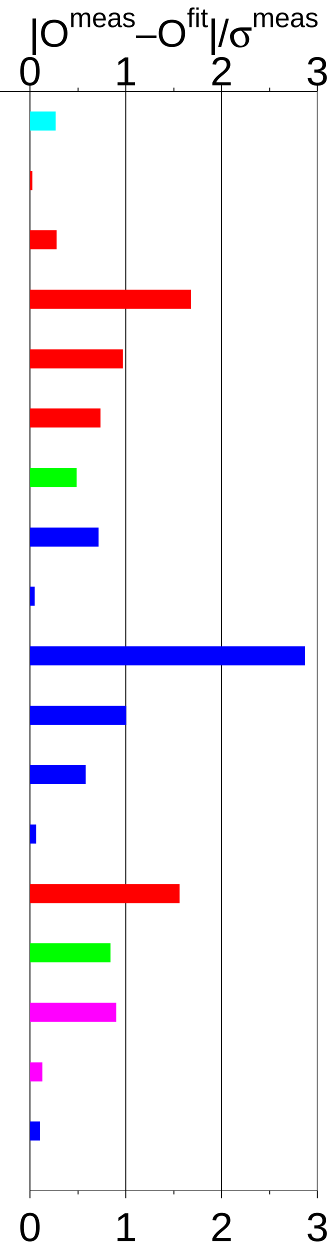
Other observables

- $\alpha(m_{\mathrm{Z}}^2)$: running of α from e^+e^- cross section at low energy to account for QED corrections
- Some other observables with smaller sensitivity

❸ Predictions in the Standard Model

- All data are fit with m_H and α_s as unconstrained parameters (+ few technical fit parameters to account for correlations)
- Theory predictions are complete 2-loop
- Overall agreement with the SM is good
  $\chi^2/\text{ndf} = 17.3/13$
  $\text{prob}(\chi^2) = 18\%$

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4958
σ^0_{had} [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.743
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01644
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21582
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.399 ± 0.025	80.376
Γ_W [GeV]	2.098 ± 0.048	2.092
m_t [GeV]	172.4 ± 1.2	172.5



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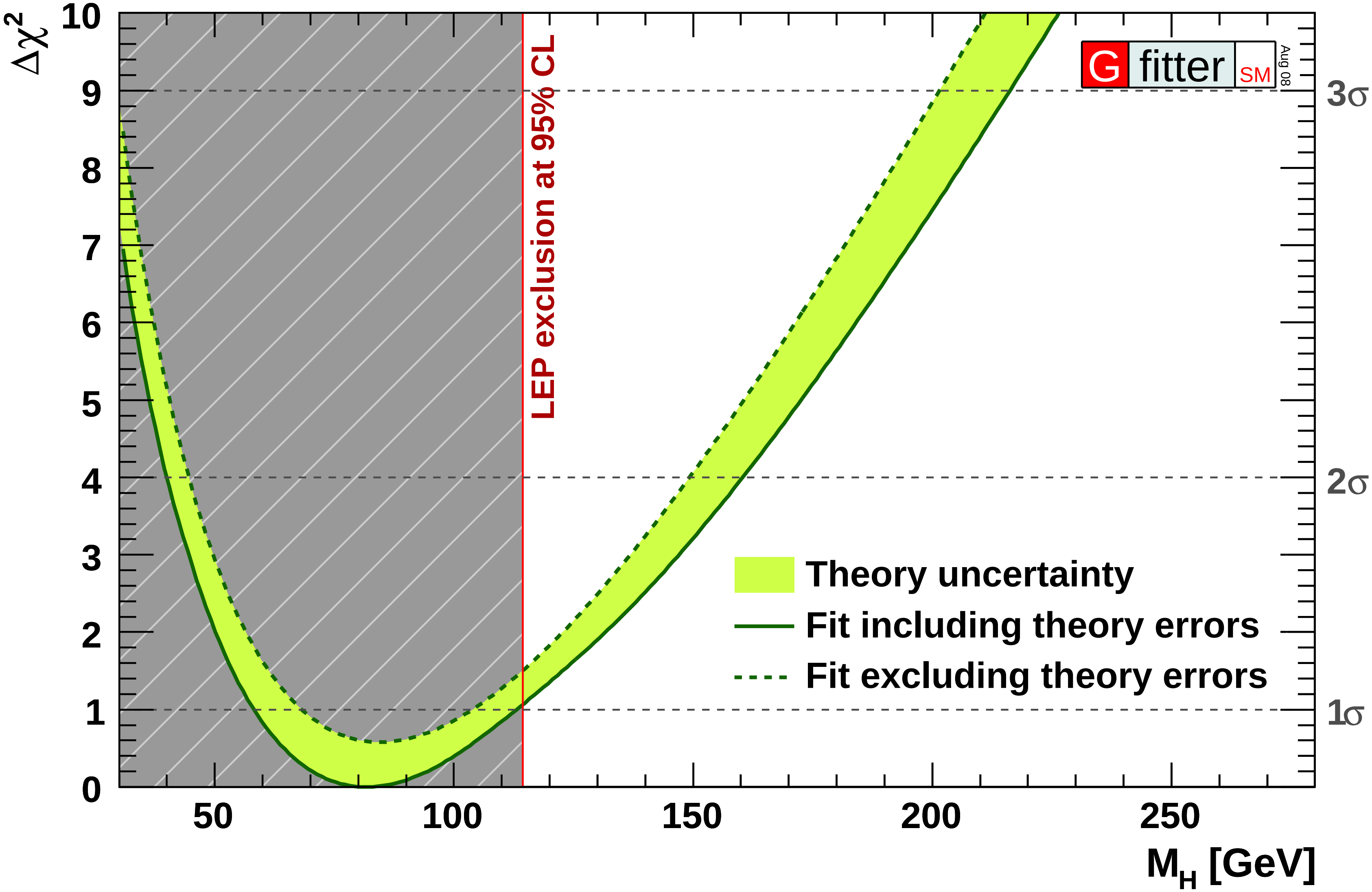
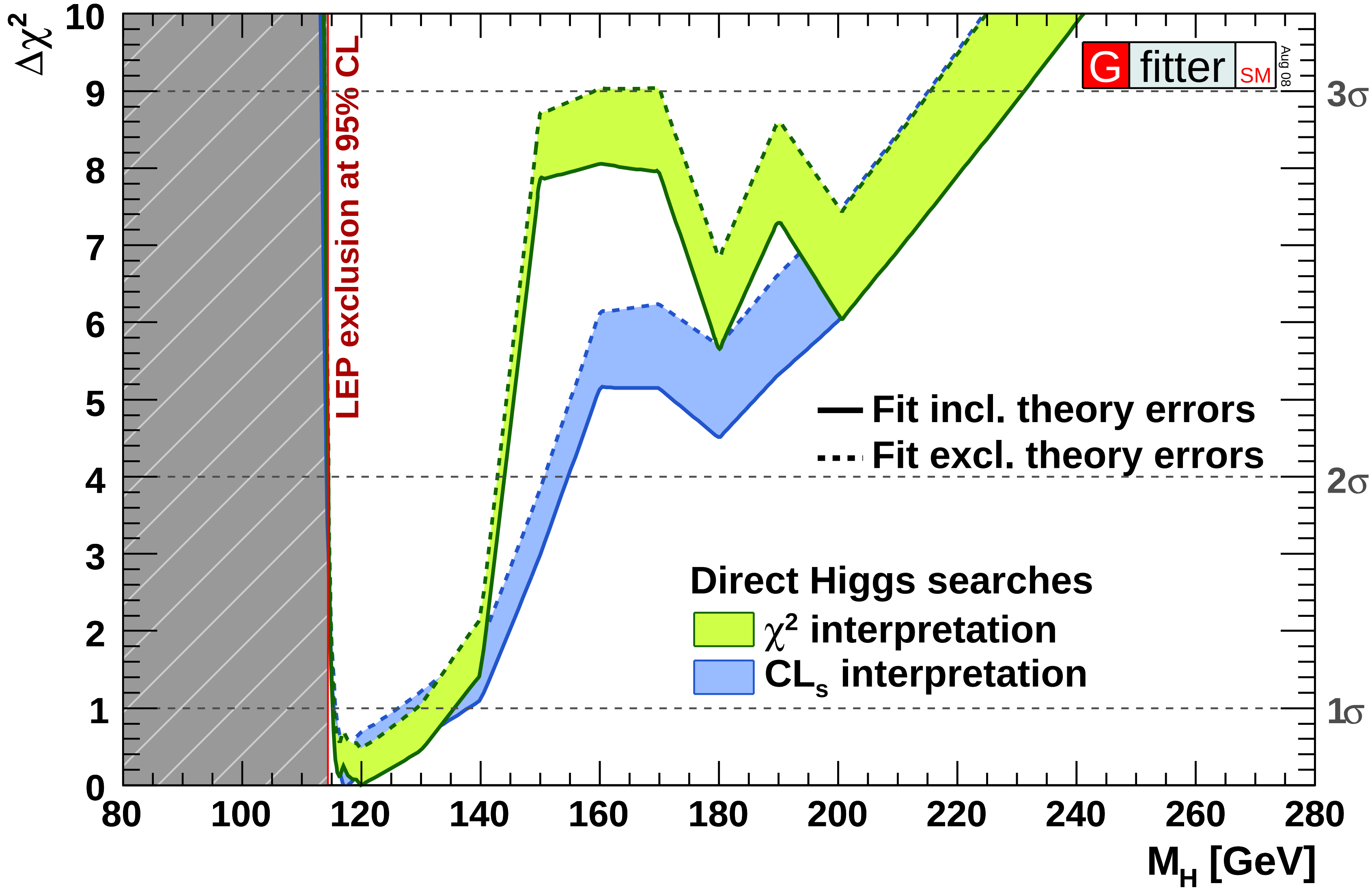
Data indicate that Higgs is light



$m_{\mathrm{H}} < 200\,\mathrm{GeV}$ strongly favoured by the data

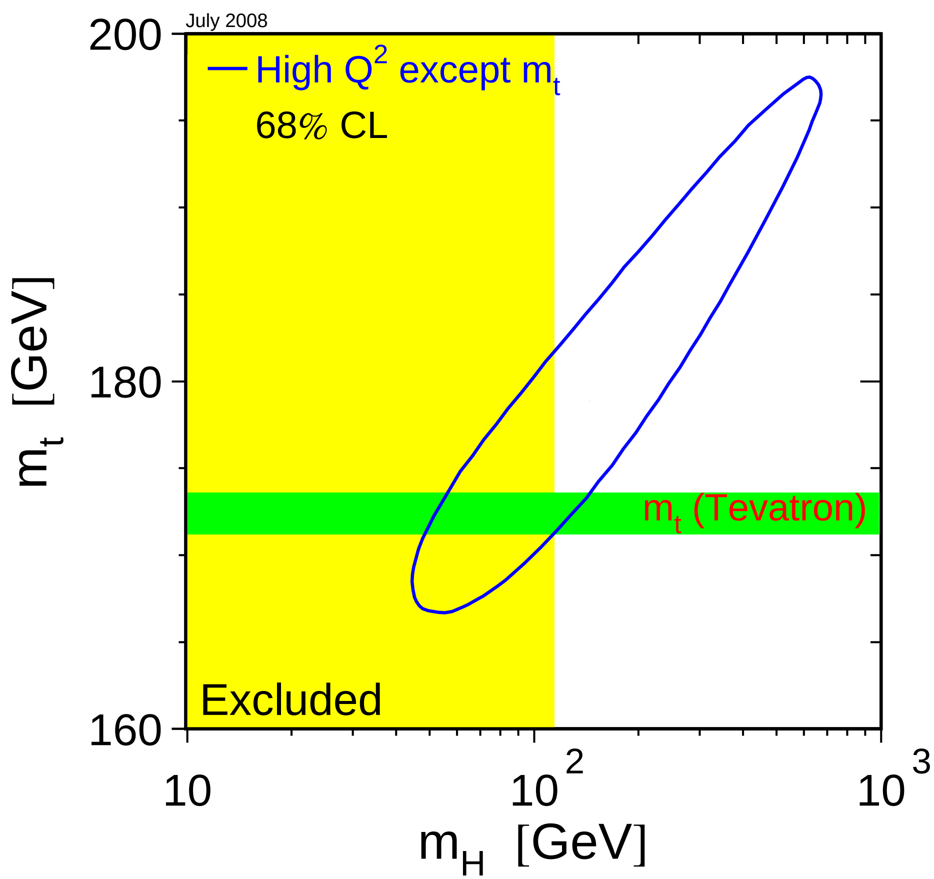
This statement gets strengthened if combined with the direct searches



The role of the Tevatron

Tevatron contribution: m_W, m_t

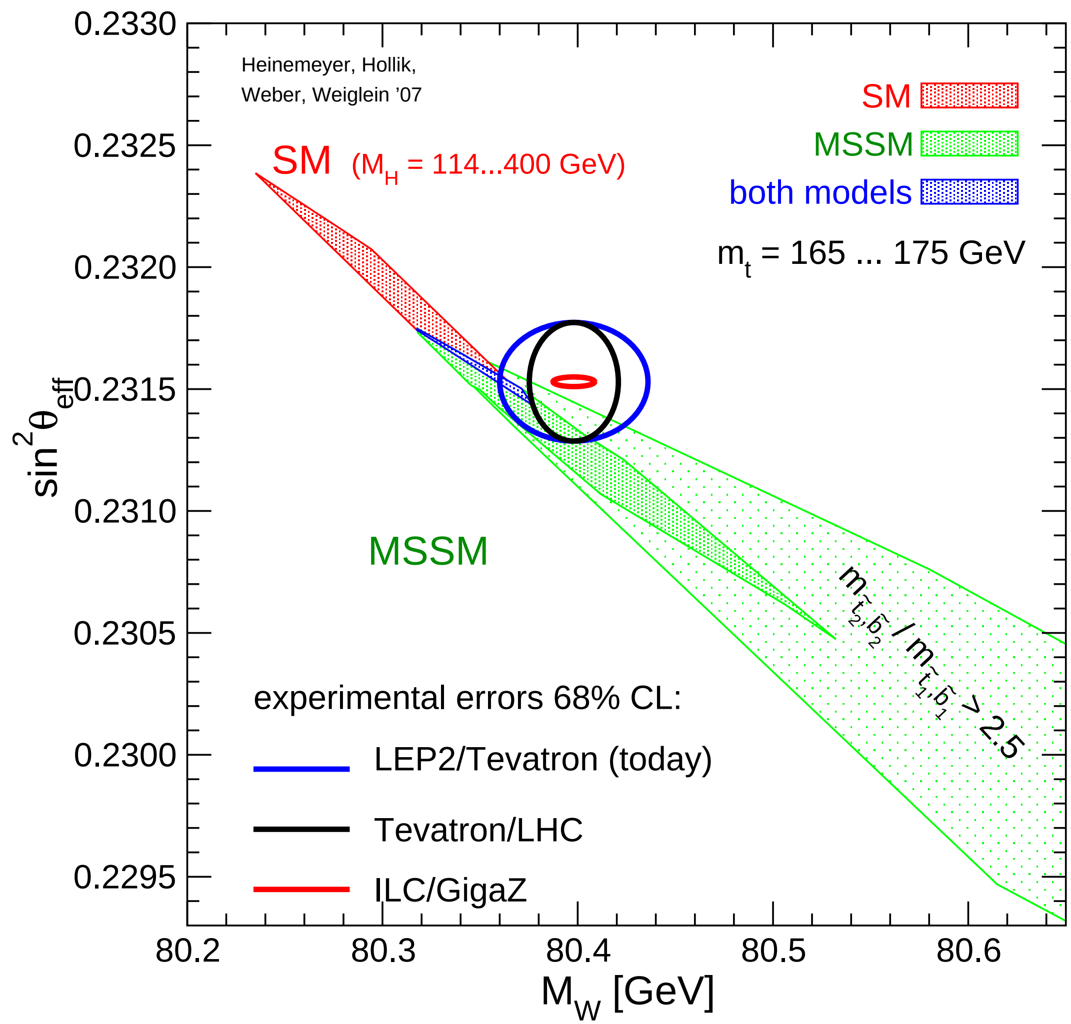
- m_W: dropping Tevatron m_W doesn't change errors significantly
- m_t: dropping m_t almost triples the log m_H error, improving m_t doesn't help at the moment



❹ Predictions beyond the Standard Model

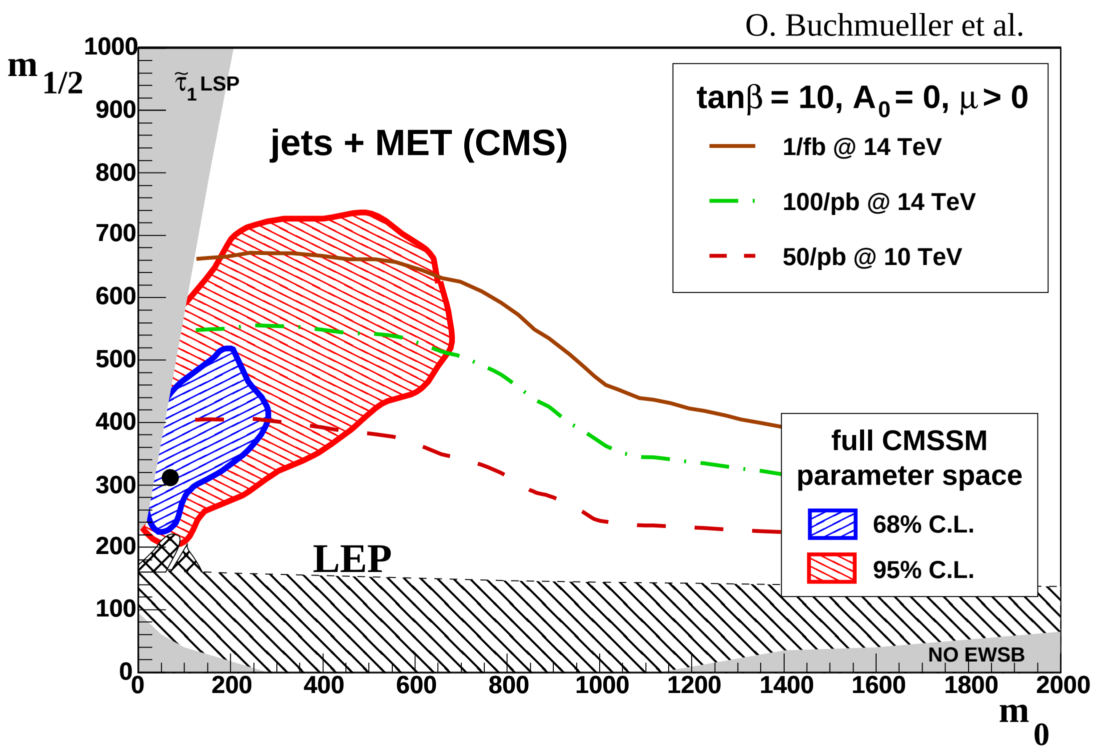
SUSY

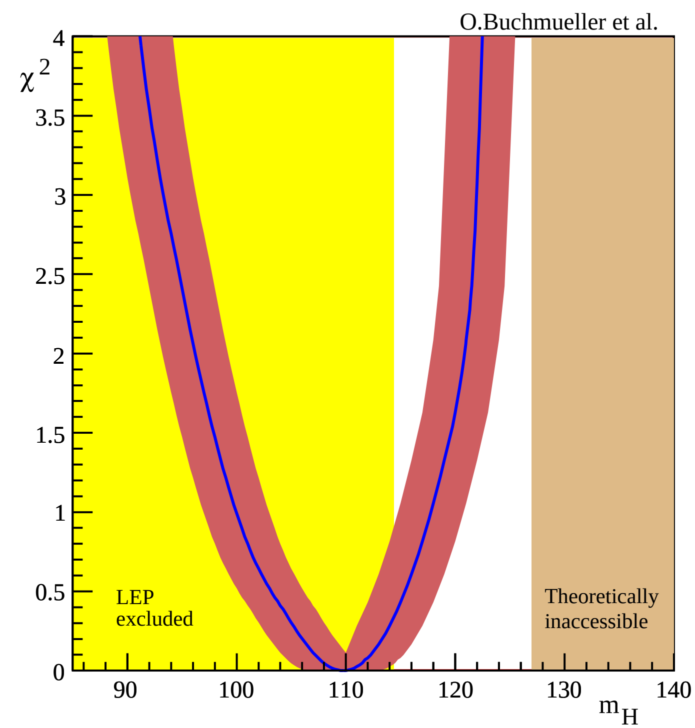
- SUSY is a fully calculable theory, so similar fits can be done
- SUSY is a decoupling theory
  ⇒ heavy SUSY looks exactly like SM
- High energy data are consistent with the SM with a slight preference to SUSY
  ⇒ no meaningful constraints are possible



Recent fits add new observables:

- $g_\mu - 2$: if hadronic vacuum polarisation is taken from e^+e^-
  $\sim 3\sigma$ from SM, favouring light SUSY
  (however if taken from τ-decays much more consistent with SM)
- Dark matter density: Assuming that LSP accounts for all dark matter favours light SUSY
- $BR(b \to s\gamma)$ is 1σ above SM ➟ small pull towards light SUSY
- Result: relatively low m_0, $m_{1/2}$ at moderate $\tan\beta$

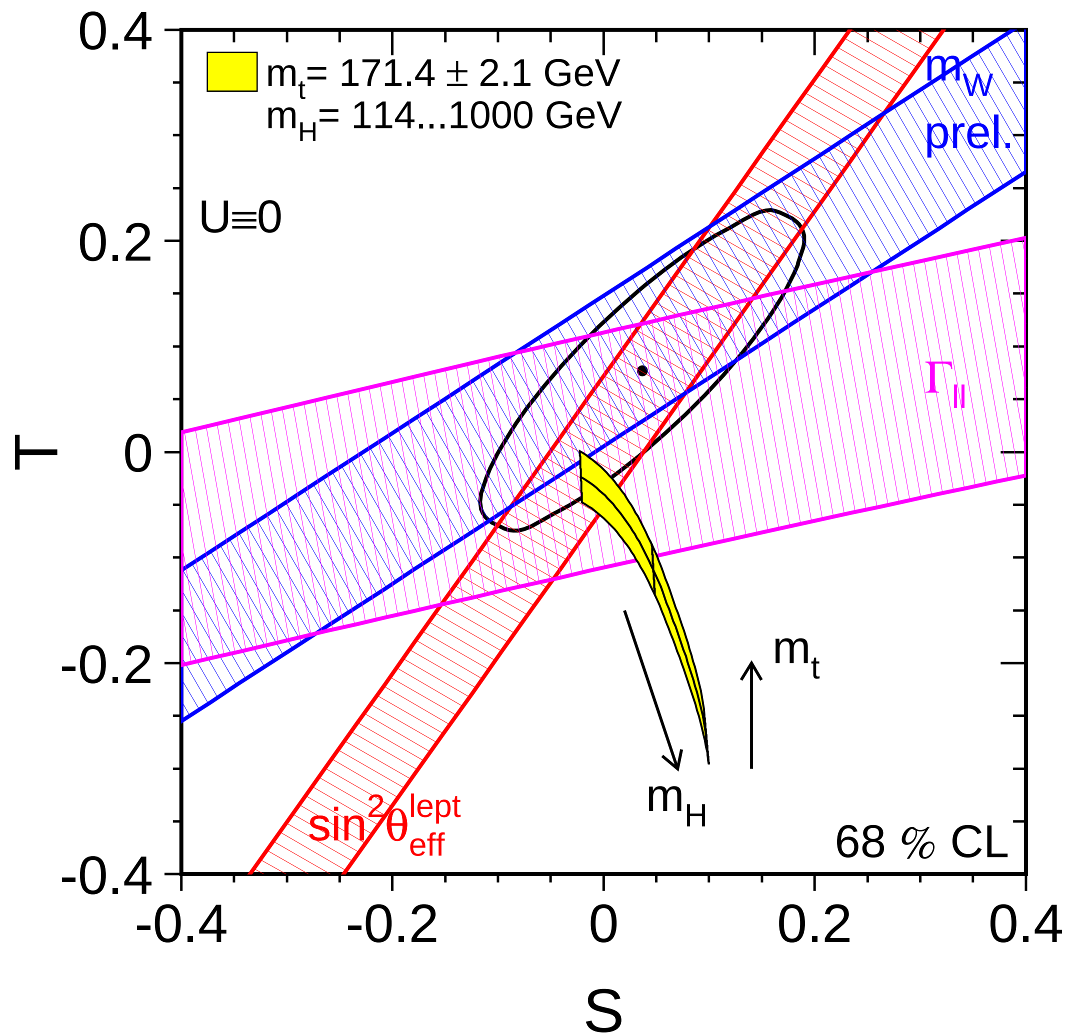




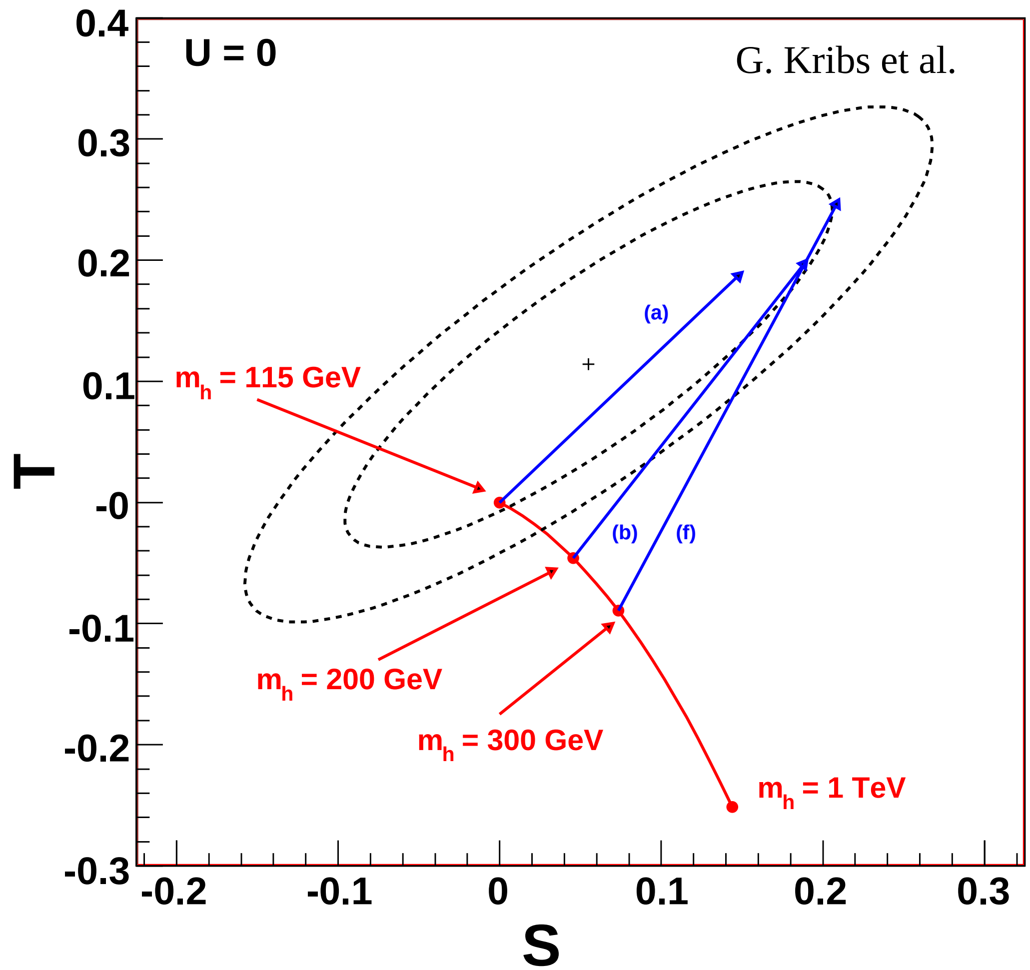
Model independent approach

- STU parameters parametrise loop effects in a model independent way
- Most models predict U=0, so this constraint is often used

- $\sin^2\theta^l_{eff}$ gives narrowest band
- Γ_ℓ ideal complement, however of limited precision
- m_W important additional constraint



- In the SM of course the m_H limit is found back
- However if news physics can be arrange to provide the right ΔT and ΔS a heavier Higgs can easily be accommodated
- Example: 4th generation with $m_U = 400\,\mathrm{GeV}$, $m_D = 325\,\mathrm{GeV}$, $m_\mathrm{H} = 300\,\mathrm{GeV}$ well consistent with precision data



❺ Conclusions

- The SM is still consistent with the precision data
- Inside the SM a light Higgs is strongly preferred
- Light SUSY is favoured by some low energy observables
- In more general models a heavier Higgs can be compensated if the new free parameters are adjusted accordingly