Ananda Landwehr
Max-Planck Institut für Physik

Higgs and Electroweak Physics

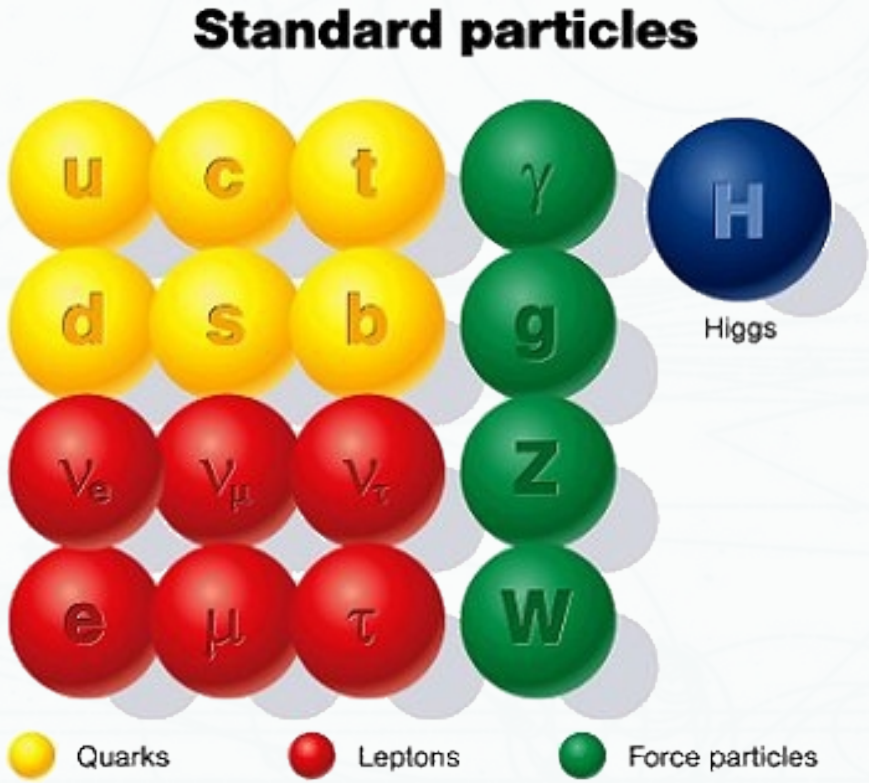
Young Scientists Workshop 2010
Ringberg Castle

Outline

- Part I: Models
  - Higgs sector of the Standard Model (SM)
  - Higgs sector of the MSSM
- Part II: Observables
  - Precision Observables
  - Standard Model Fit
  - MSSM Fit

Part I: Models

Higgs Mechanism in the Standard Model



$$Q = \begin{pmatrix} u_L \\ d_L \end{pmatrix}, \; L = \begin{pmatrix} e_L \\ \nu_L \end{pmatrix},$$

$$u_R, \; d_R, \; e_R$$

- Mass term not possible

$$\mathcal{L}_{\mathrm{F}} = \bar{\psi}(i\gamma^\mu \mathrm{D}_\mu - \cancel{m})\psi$$

$$\mathrm{D}_\mu = \partial_\mu - ig_1 \frac{Y}{2} B_\mu$$

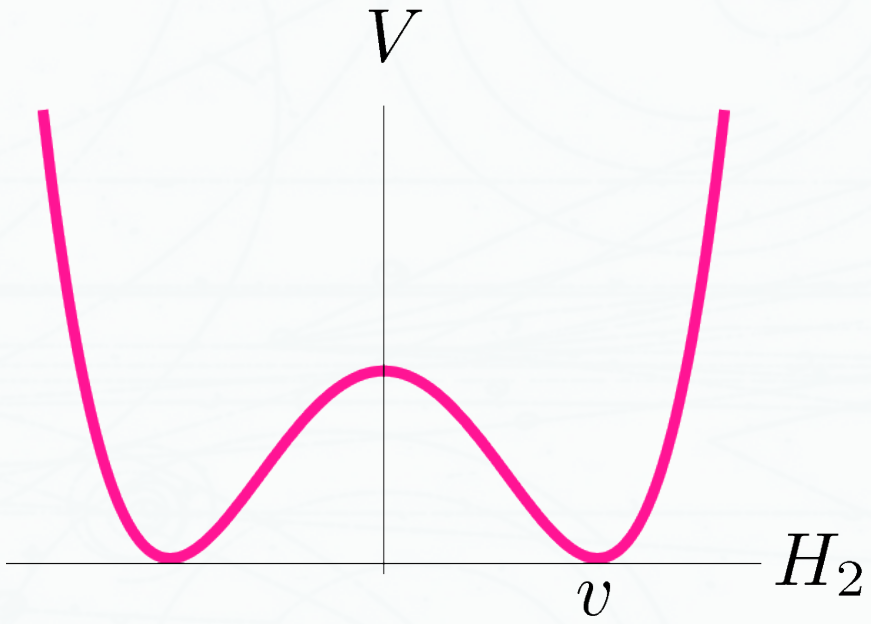
$$-ig_2 \frac{\tau^i}{2} W_\mu^i$$

- Higgs mechanism:

Interaction with scalar field, whose Ground state brakes

$$\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y \to \mathrm{U}(1)_{\mathrm{em}}$$

Higgs mechanism in the Standard Model



$$\mathcal{L}_{\mathrm{H}} = (\mathrm{D}_\mu H)^\dagger (\mathrm{D}^\mu H) - V(H)$$

$$V(H) = \mu^2 H^\dagger H + \lambda |H^\dagger H|^2$$

$$\langle H \rangle = \begin{pmatrix} 0 \\ \sqrt{-\frac{\mu^2}{2\lambda}} \end{pmatrix} \equiv \begin{pmatrix} 0 \\ v \end{pmatrix}$$

- Gauge boson masses:

$$M_W = \frac{g_2\, v}{\sqrt{2}}, \; M_Z = \frac{M_W}{\cos\theta_W}$$

- Fermion masses

$$y\,(\bar{u}_L, \bar{d}_L) \begin{pmatrix} H_1 \\ H_2 \end{pmatrix} d_R$$

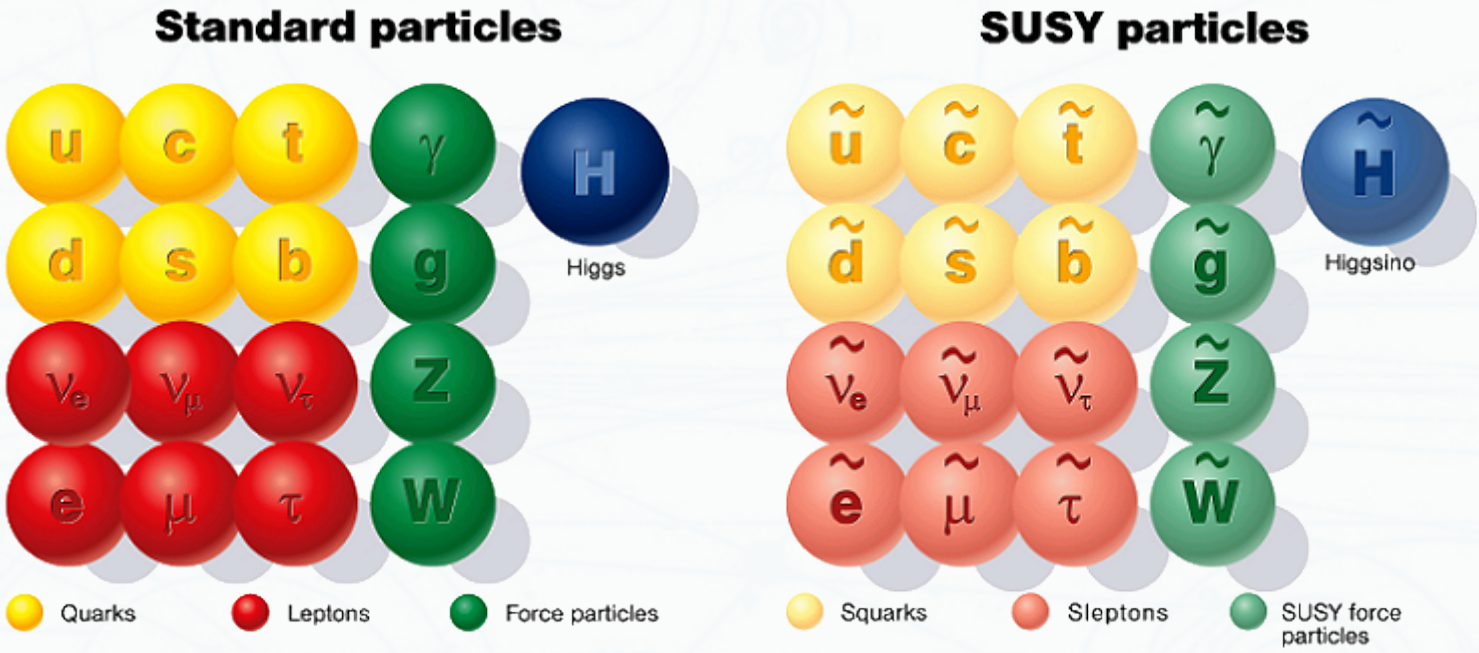
$$\rightarrow y_d\, v\, \bar{d}_L\, d_R$$

- Higgs boson

$$m_{h^0} = \sqrt{-2\mu^2}$$

- free parameter: m_{h^0}

Higgs Mechanism in the MSSM



- Each SM particle gets MSSM partner with Spin $\pm 1/2$
- 2 Higgs doublets H_1 and H_2

Higgs Mechanism in the MSSM

- MSSM Higgs Potential:

  All possible Higgs self-interactions

$$V = m_1^2 \bar{H}_u H_u + m_2^2 \bar{H}_d H_d - \epsilon^{ij}(m_{12}^2 H_{ui} H_{dj} + \text{h.c.})$$
$$+ \frac{1}{8}(g_1^2 + g_2^2)(\bar{H}_u H_u - \bar{H}_d H_d)^2 + \frac{1}{2} g_2^2 |\bar{H}_u H_d|^2$$

- Minimum: $\langle H_u \rangle = \begin{pmatrix} 0 \\ v_u \end{pmatrix}, \ \langle H_d \rangle = \begin{pmatrix} v_d \\ 0 \end{pmatrix}, \ \tan\beta = \frac{v_u}{v_d}$

  5 Higgs particles: $h^0, H^0, H^\pm, A^0$

Higgs Mechanism in the MSSM

$$V = m_1^2 \bar{H}_u H_u + m_2^2 \bar{H}_d H_d - \epsilon^{ij}(m_{12}^2 H_{ui} H_{dj} + \text{h.c.})$$
$$+\frac{1}{8}(g_1^2 + g_2^2)(\bar{H}_u H_u - \bar{H}_d H_d)^2 + \frac{1}{2} g_2^2 |\bar{H}_u H_d|^2$$

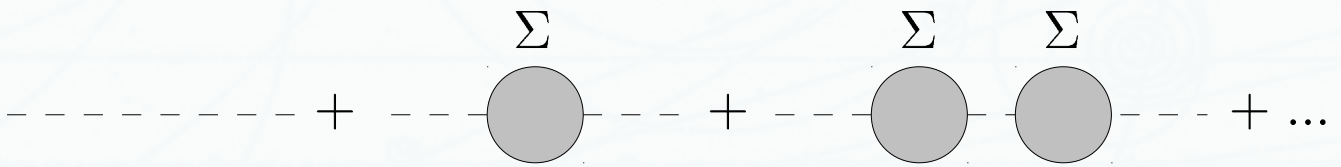
- Free parameters: $m_1^2, m_2^2, m_{12}^2 \rightarrow m_{A^0}, \tan\beta$
- Other Higgs masses depend on these parameters !!!

$$m_{h^0}^2 = \frac{1}{2}\left((m_{A^0}^2 + m_Z^2) - \sqrt{(m_{A^0}^2 - m_Z^2)^2 + |\kappa|} \right) \leq m_Z^2$$

- But from experiment (LEP) $m_{h^0} > 114\,\text{GeV} > m_Z$

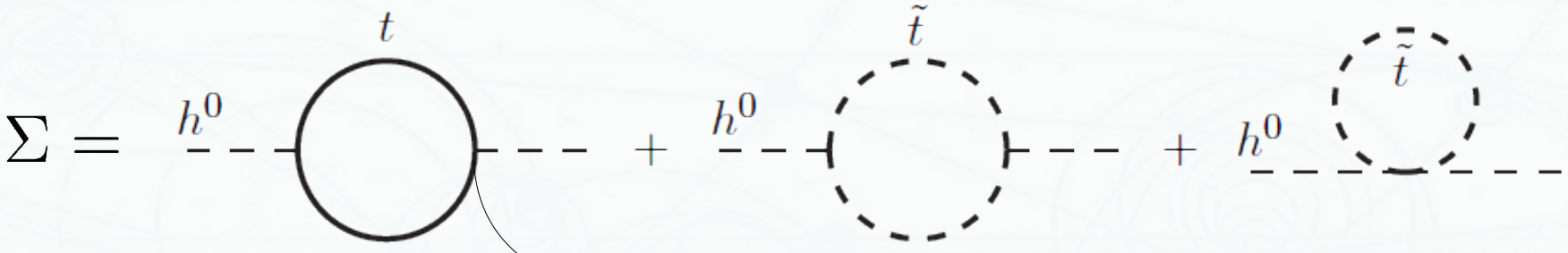
MSSM Higgs Boson Mass

- Loop Corrections to Higgs propagator



$$= \frac{i}{p^2 - m_{h^0}^2 + \Sigma}$$

- Which are the big corrections?

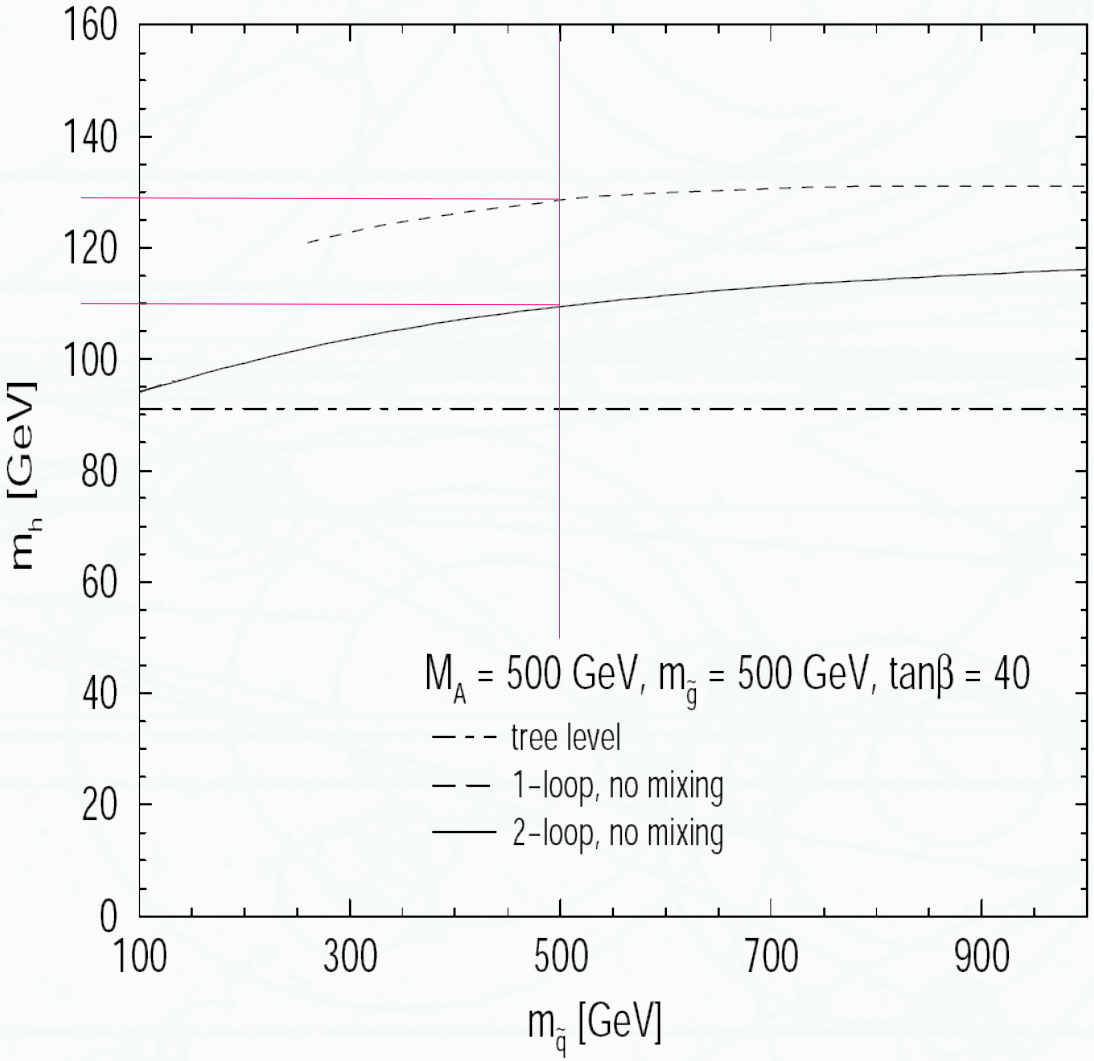


$$= \frac{3\, m_t^4}{2\pi^2\, v^2\, \sin^2\beta} \log(\ldots)$$

$$\sim y_t\, H_u\, \bar{Q}_t\, t_R$$

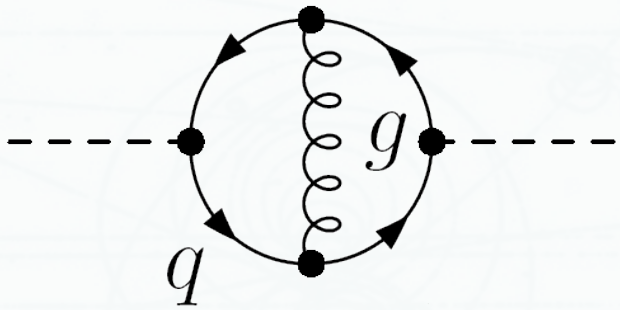
$$y_t\, v_u = m_t \;\rightarrow y_t = \frac{m_t}{v_u} \sim 1$$

MSSM Higgs Boson Mass



- 1-loop corrections ~ 40 GeV

→ 2-loop corrections



[Heinemeyer et. al., 1998]

Higgs: SM vs MSSM

SM

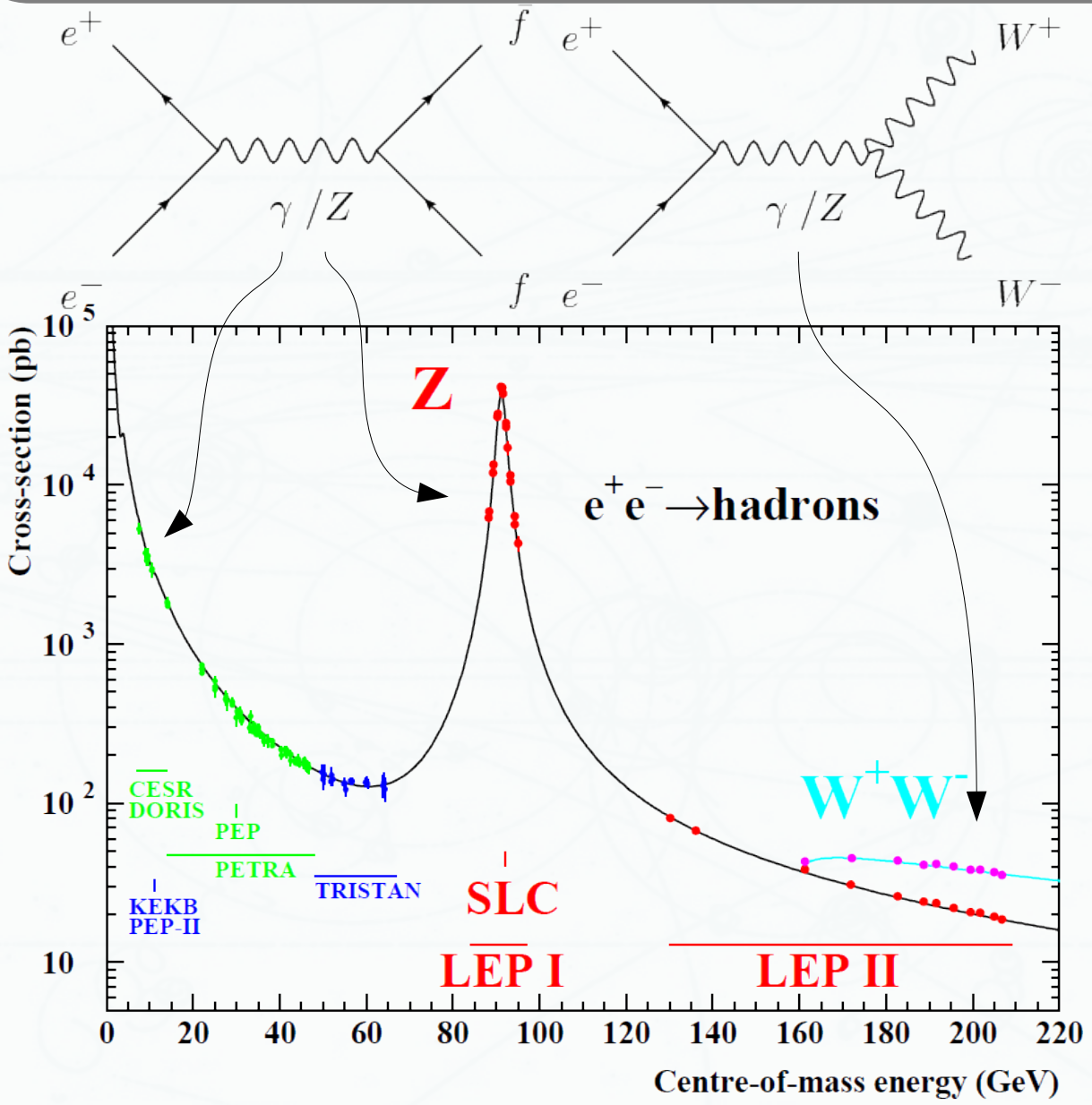
- 1 Higgs doublet
  1 Higgs boson
- Higgs potential inserted by hand
- Higgs boson mass: free parameter

MSSM

- 2 Higgs doublets
  5 Higgs bosons
- Higgs potential appears naturally
- Lightest Higgs boson mass: dependent parameter
- Radiative corrections

Part II: Observables

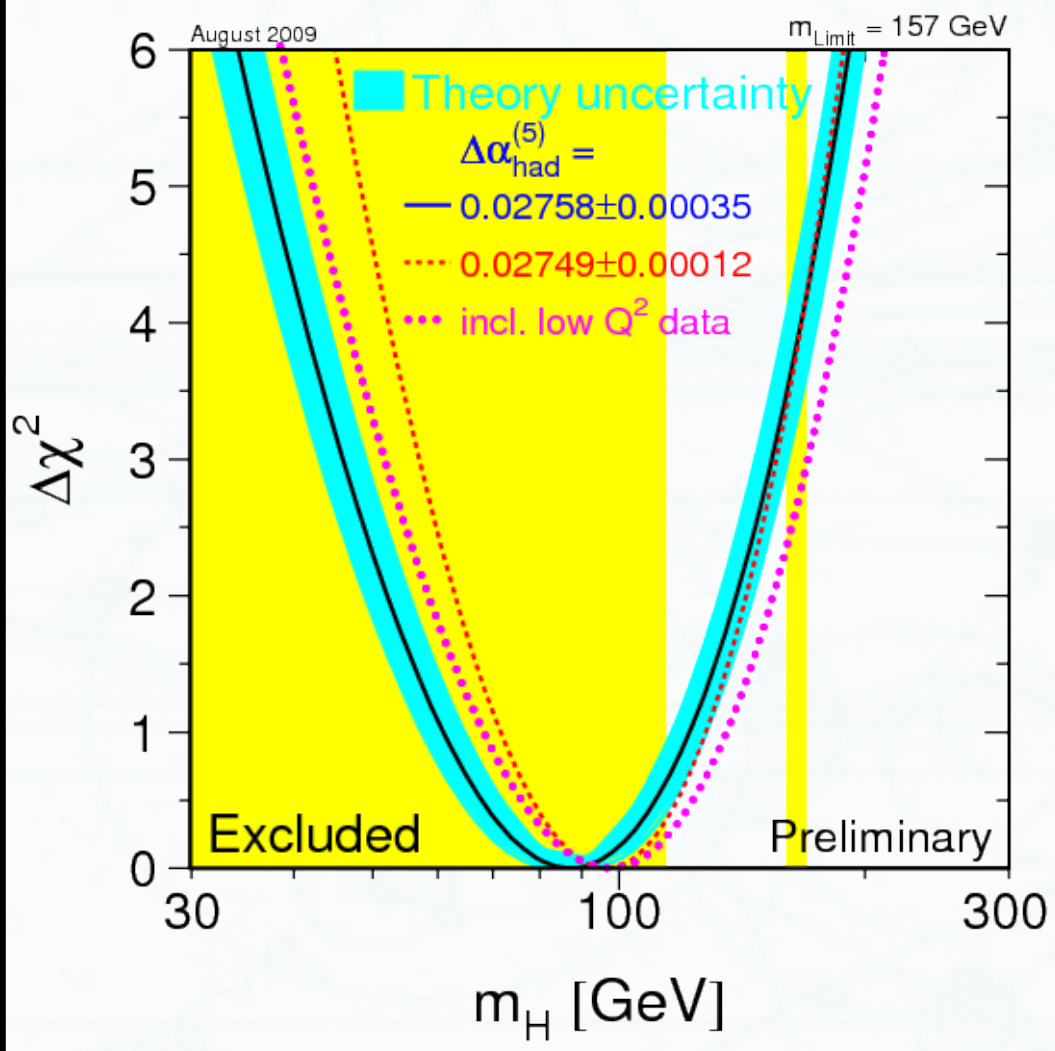
Precision Observables



- LEP I:
  $m_Z,\ \Gamma_Z$
- LEP II + Tevatron:
  $m_W,\ \Gamma_W$
- Tevatron:
  m_t

[The LEP Electroweak Working Group]

Blueband Plot



[The LEP Electroweak Working Group]

- SM input parameters:

$$\{m_t,\ m_Z,\ \alpha\left(m_Z^2\right)\},\ m_{h^0}$$

- Calculate:

$$\{\Gamma_Z, m_W, \Gamma_W, m_t, ...\}$$

- Measure:

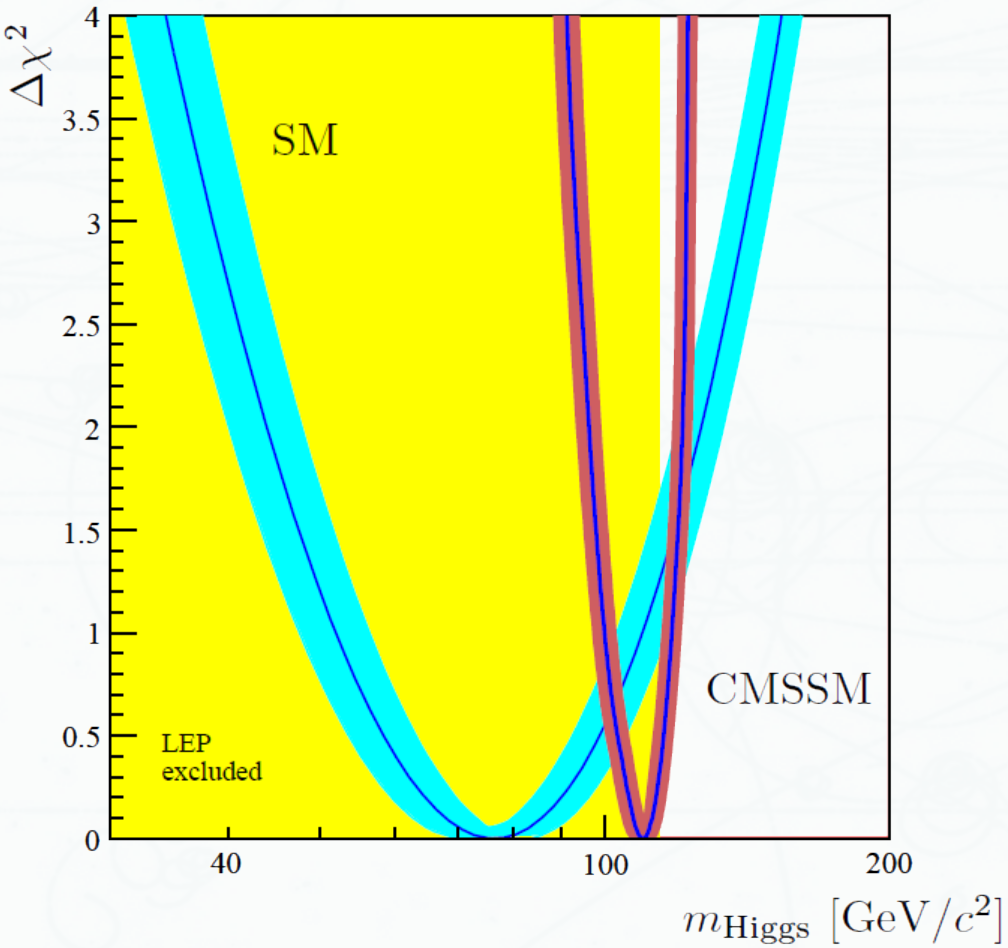
$$\{\Gamma_Z, m_W, \Gamma_W, m_t, ...\}$$

$$\{m_t,\ m_Z,\ \alpha\left(m_Z^2\right)\}$$

- Minimize χ^2

MSSM Fit

- SM Parameters: $\{m_t,\ m_Z,\ \alpha\left(m_Z^2\right)\},\ \cancel{m_{h^0}}$
- CMSSM Parameters: $\{M_0,\ M_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sign}\,(\mu)\}$



- Fit probability
  SM: 18 %
  CMSSM: 20 %

- Preferred Higgs mass

$$m_{h^0}^{\mathrm{SM}} = 87^{+35}_{-26}\ \mathrm{GeV}$$

$$m_{h^0}^{\mathrm{CMSSM}} = 110^{+11}_{-13}\ \mathrm{GeV}$$

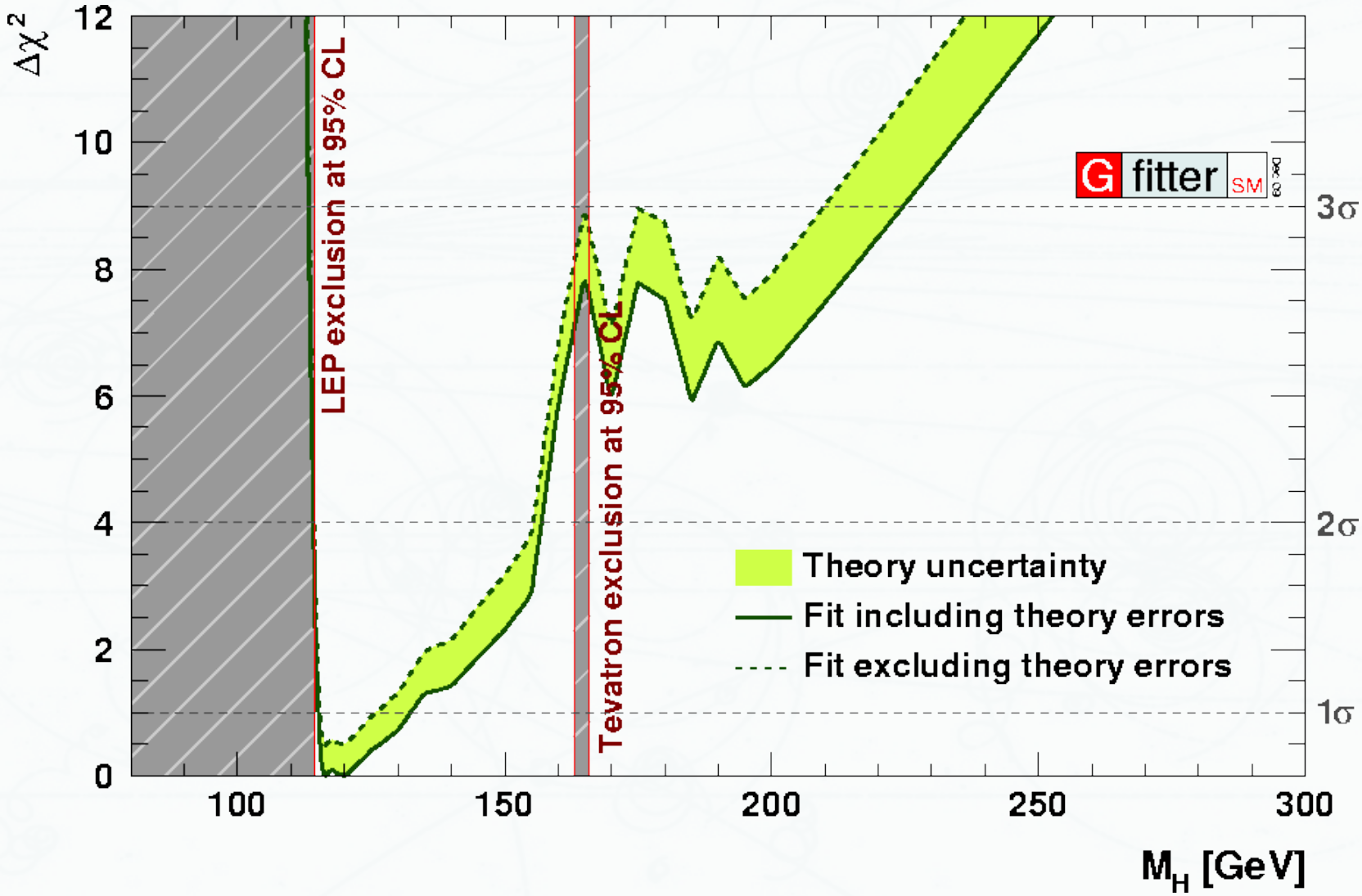
[arXiv:0707.3447v2]

Conclusions

- SM: Higgs boson mass → free parameter
- MSSM: lightest Higgs boson mass → dependent parameter
  - Radiative corrections are important
- Precision observables
  - SM: Higgs boson mass ~ 87 GeV preferred
  - CMSSM: Higgs boson mass ~ 110 GeV preferred

THANK YOU

Blueband Plot with Higgs Mass Exclusion



[Gfitter]

Parameters

[The LEP Electroweak Working Group]