

ElectroWeak Symmetry Breaking: where do we stand?



- The Standard Model of the elementary particle interactions (status of)
- The EWSB problem defined
- A proposed solution

The theory of the strong and electroweak interactions among elementary particles

$$\begin{aligned} L_{\text{SM}} = & \bar{\psi} \not{D} \psi + F_{\mu\nu} F_{\mu\nu} & 1. \\ & + \lambda \bar{\psi} \psi \phi & 2. \\ & + |D_{\mu} \phi|^2 - V(\phi) & 3. \end{aligned}$$

1. the gauge sector
2. the flavour sector
3. the symmetry – breaking sector

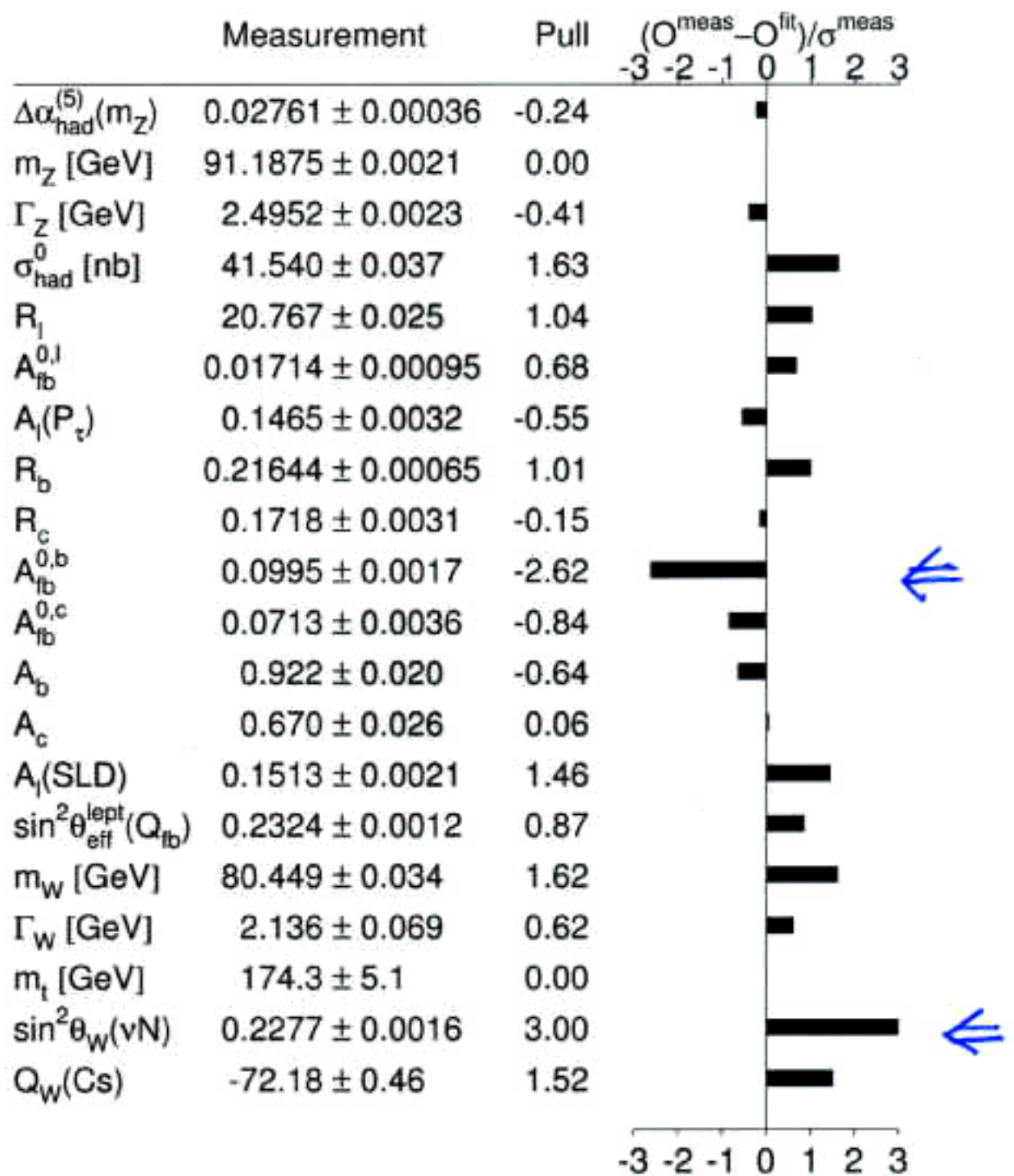
+ neutrino masses

+ ?

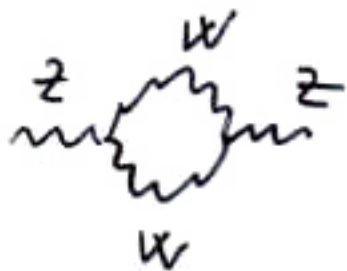
tested at
very different
level of depths,
most likely
incomplete

Electroweak Precision Tests

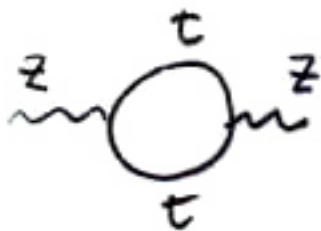
Summer 2002



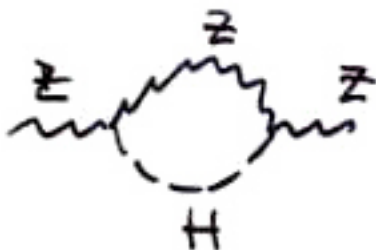
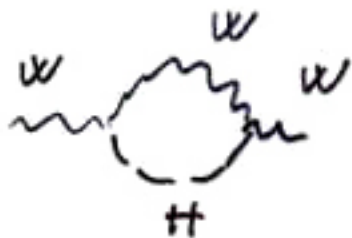
A significant evidence (not the only one) for the gauge sector of the SM



\dots



\dots



\dots



more on
these later

\dots

(a piece of the
e.w.s.b. sector as
well)

The basic constituents of matter

u	c 1974	τ 1994
d	s	b 1977
\uparrow	\uparrow	\uparrow

quarks
(each in 3 colours)

ν_e 1956	ν_μ 1962	ν_τ 2000
e 1897	μ 1937	τ 1975
\uparrow	\uparrow	\uparrow

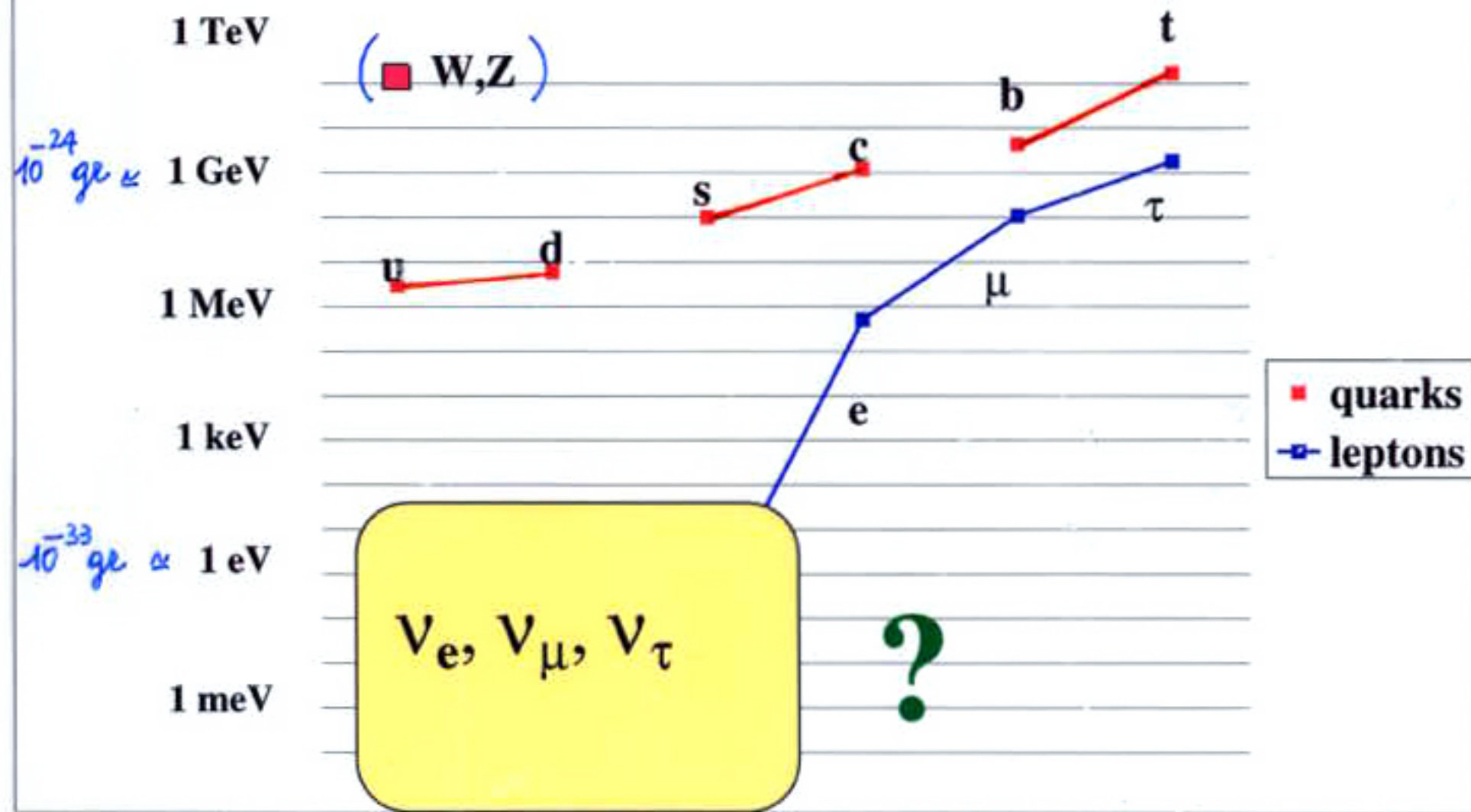
leptons

1st, 2nd, 3rd
family

most likely complete
(ν_e, μ, τ not eigenstates of mass)

A mysterious spectrum

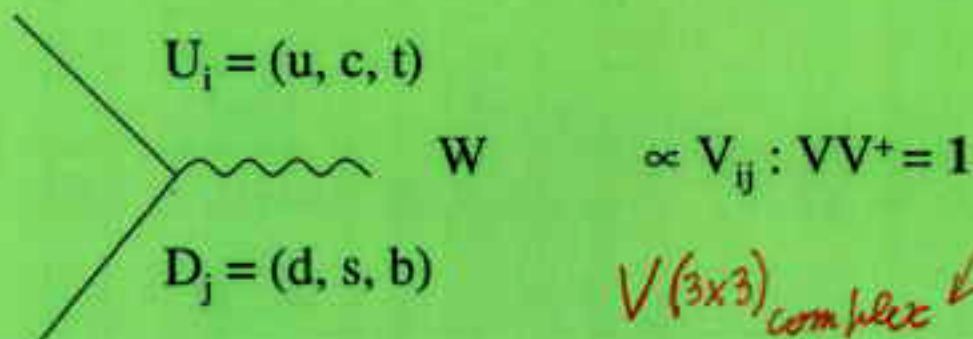
Particle Masses



The flavour sector

1937: the muon discovered *Auberson, Neddermayer*

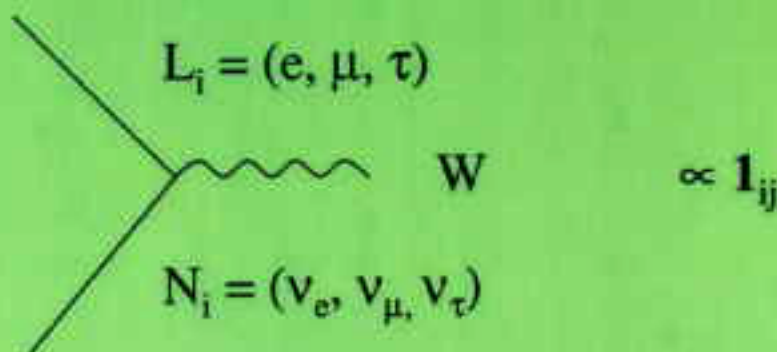
In the quark sector: All of flavour interconnections and CP violation in the weak charged current



CP
↓
B-B
asym

In the lepton sector:

Universal gauge interactions of $e - \mu - \tau$



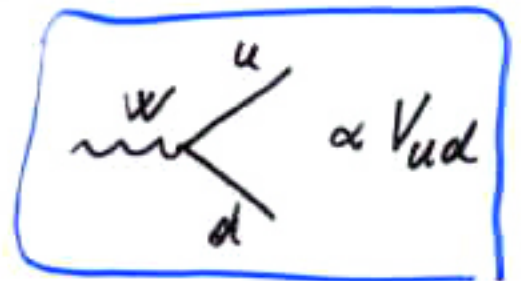
Individual lepton number conservations L_e, L_μ, L_τ
(but no neutrino masses)

P = parity $\vec{x} \rightarrow -\vec{x}$
C = conjugation $m \leftrightarrow \bar{m}$
T = time reversal

CPT unbroken
in local QFT
PAULI

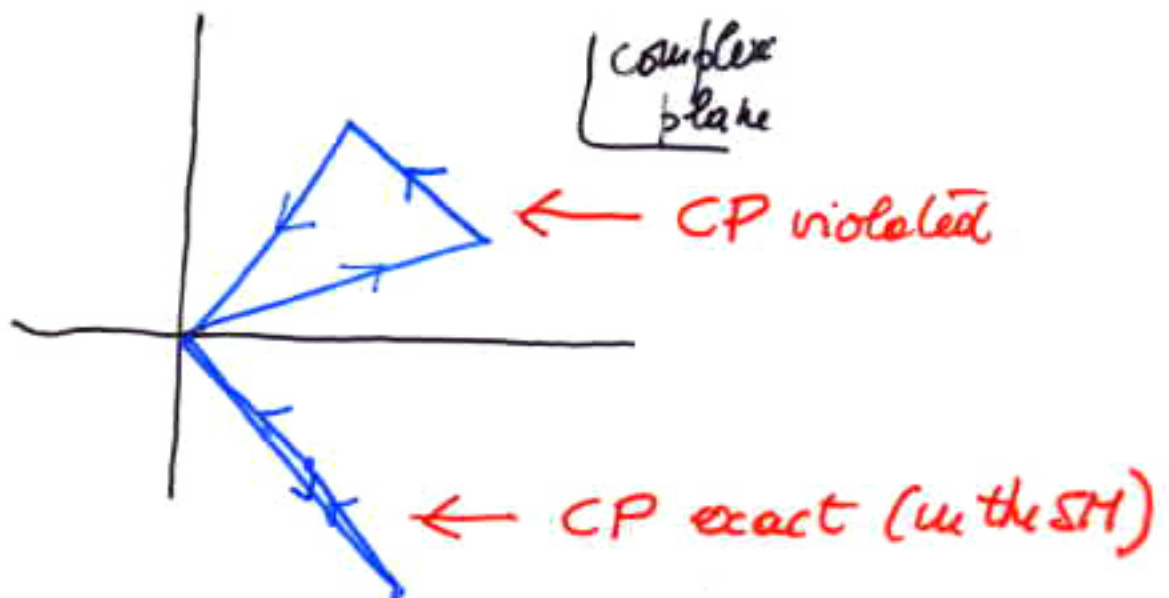
The quark flavour sector

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \text{ unitary}$$

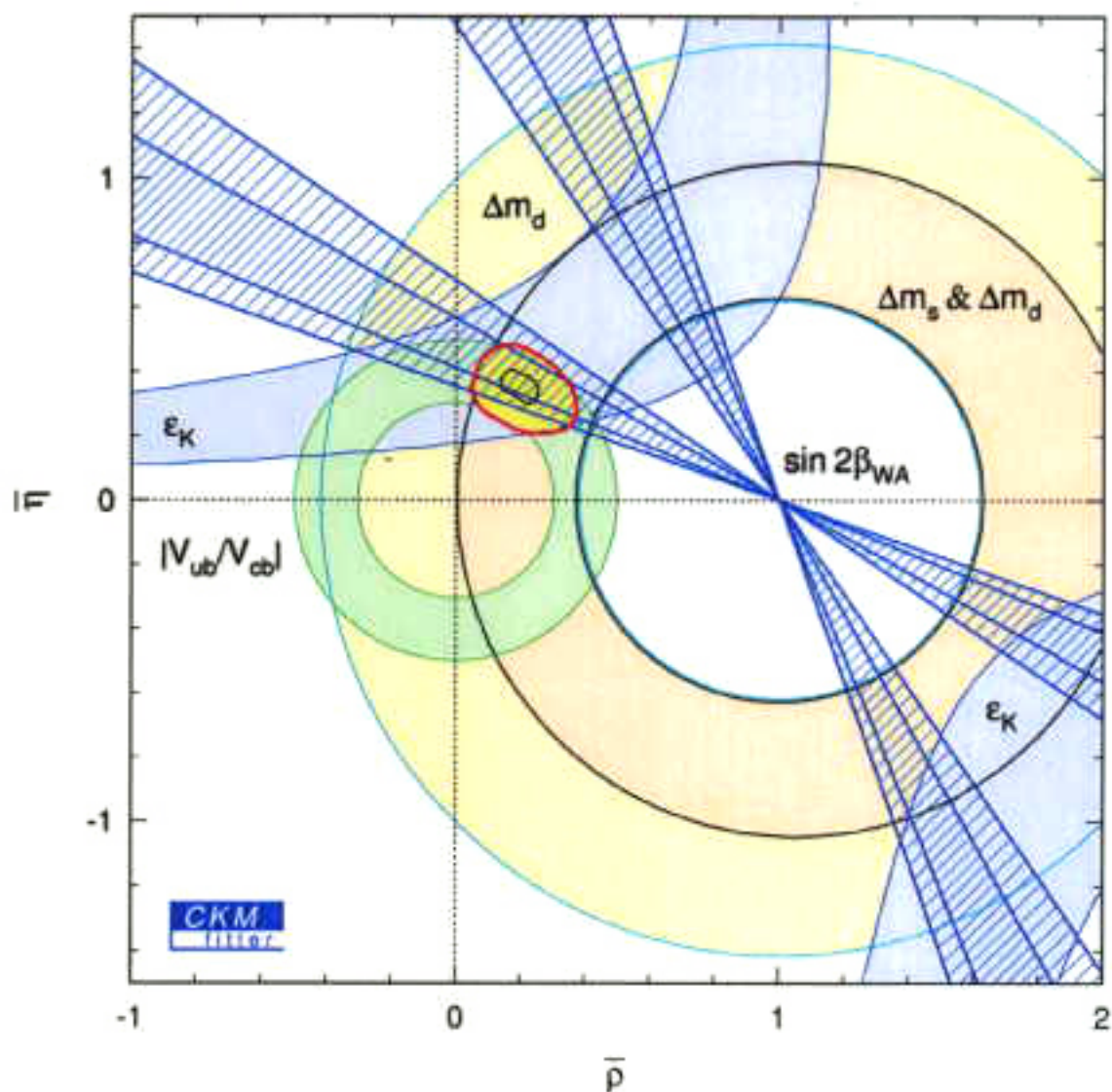


$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9970 \pm 0.0022$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



Flavour physics as of 2002



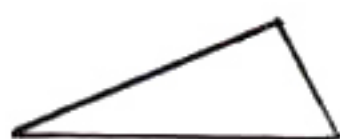
$$V_{ub}/V_{cb} \oplus \epsilon_K \oplus \Delta m_B \oplus \sin 2\beta$$

$$\oplus \epsilon'/\epsilon|_K$$

[$\epsilon'/\epsilon|_K$ established in $\Delta S=2, \Delta B=2, \Delta \mathcal{B}=1$]

r

g



L

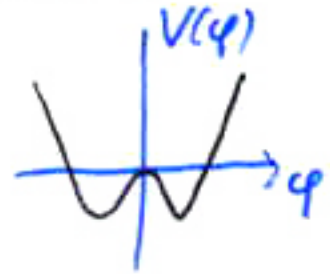
L

The symmetry breaking sector

(em : $r = \infty$; weak : $r \ll r_N$)
(no distinction between the electron and the neutrino)

A mechanism for spontaneous symmetry breaking observed in condensed matter physics

\Rightarrow A “Anderson – Higgs particle” must exist



Evidence

(qualitative) A meaningful comparison with data difficult without Higgs exchanges

(quantitative) Electroweak precision tests require a Higgs mass in the range expected

$$m_H = 77^{+70}_{-40} \text{ GeV indirect}$$
$$m_H > 114 \text{ GeV direct}$$

Prospects for discovery

The SM Higgs boson will not escape detection by a combination/progression of searches at TEVATRON/LHC, if it exists

But the Higgs boson is not the full story

What is known of the
ElectroWeak Symmetry Breaking
sector?

Not much:

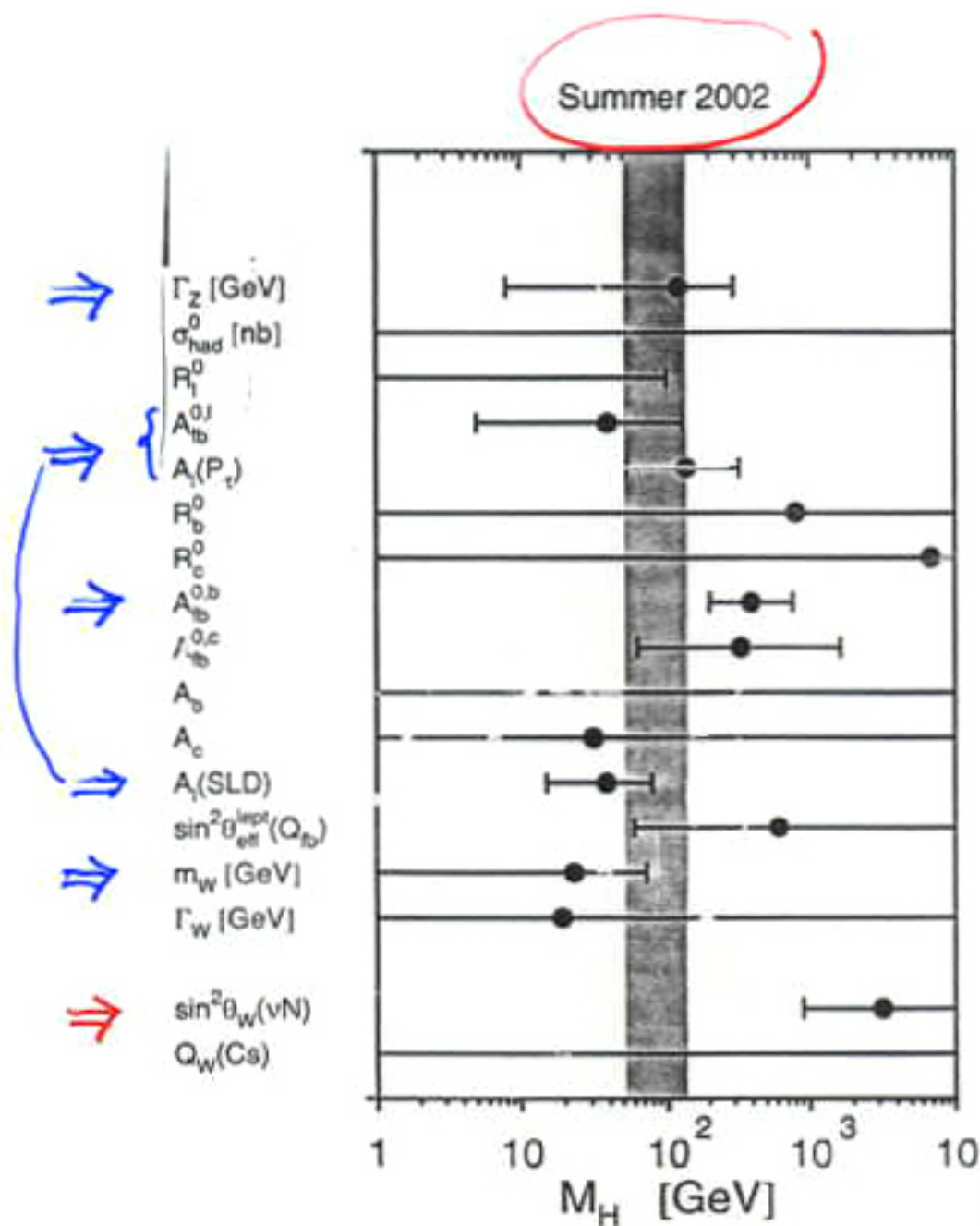
Most likely, the Higgs phenomenon
is correct

Most likely, the Higgs is light

The counterpart:

At the focus of exps. in
this decade (TEVATRON, LHC, ...)

The fit of M_H in the SM



$$m_H = 81^{+52}_{-33} \text{ GeV}$$

$$< 195 \text{ GeV (95\% CL)}$$

4 main observables:

$$\Gamma_Z, A_{lept}, A_b, m_W$$

A problem in νN scattering?

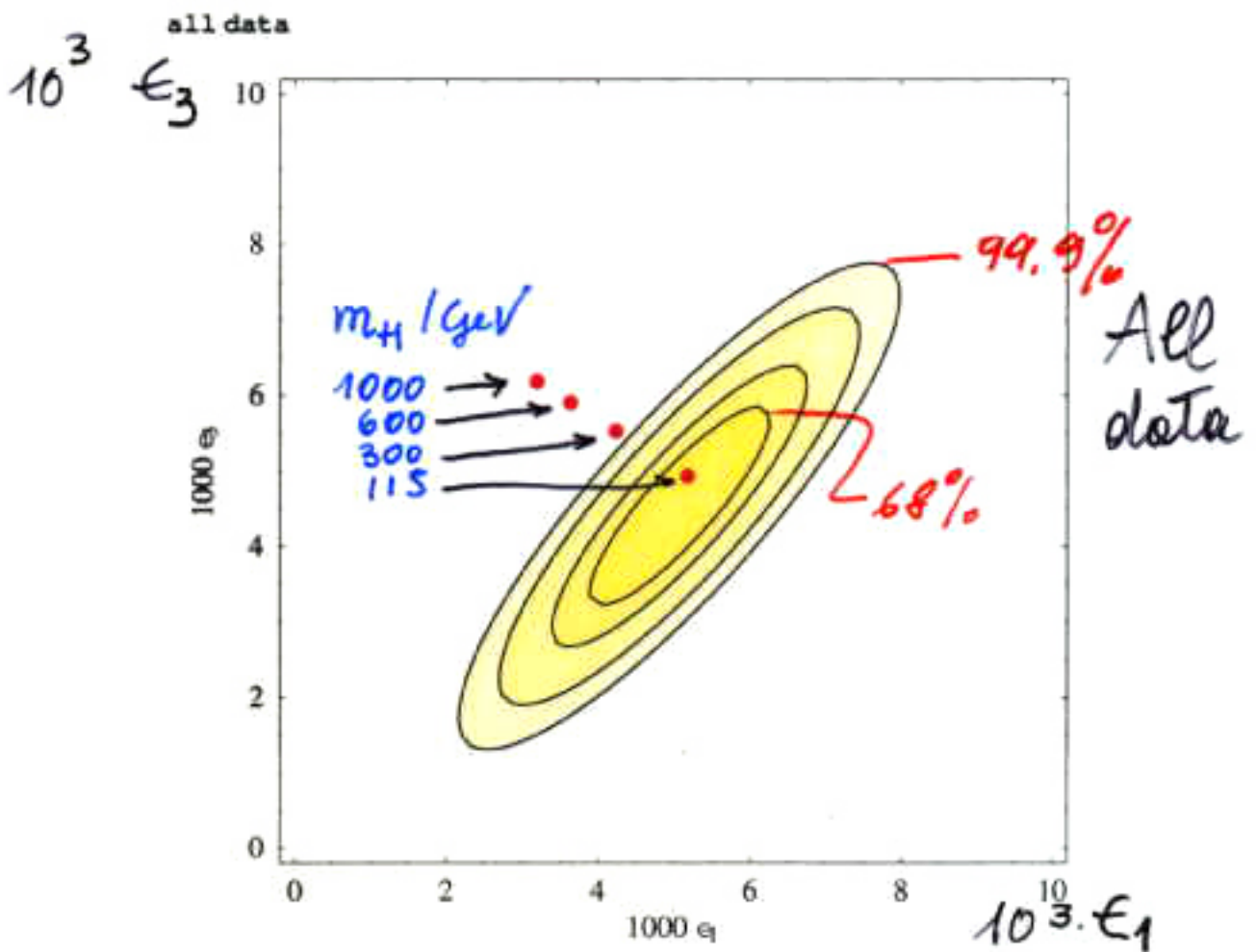
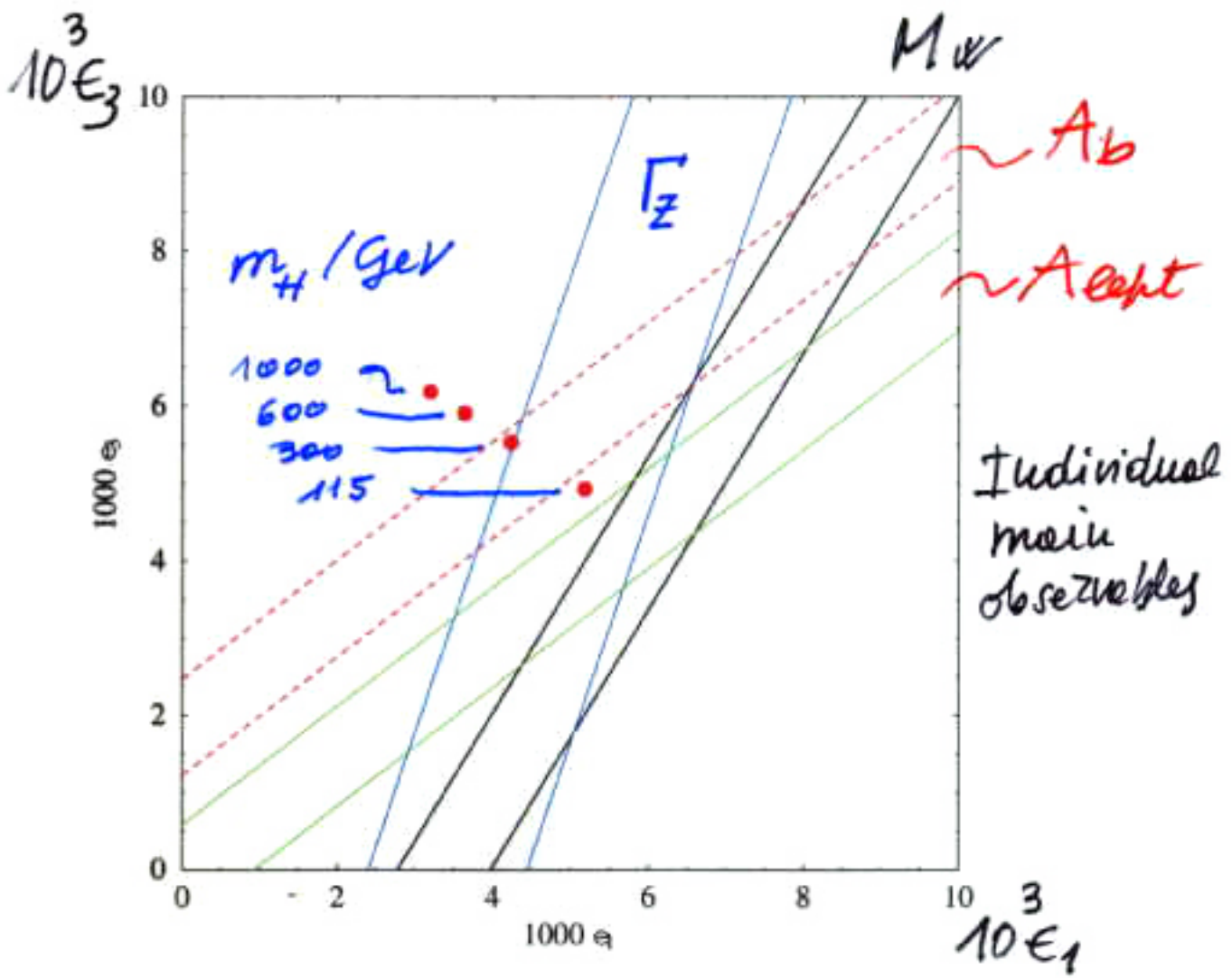
Effects of virtual Higgs exchanges



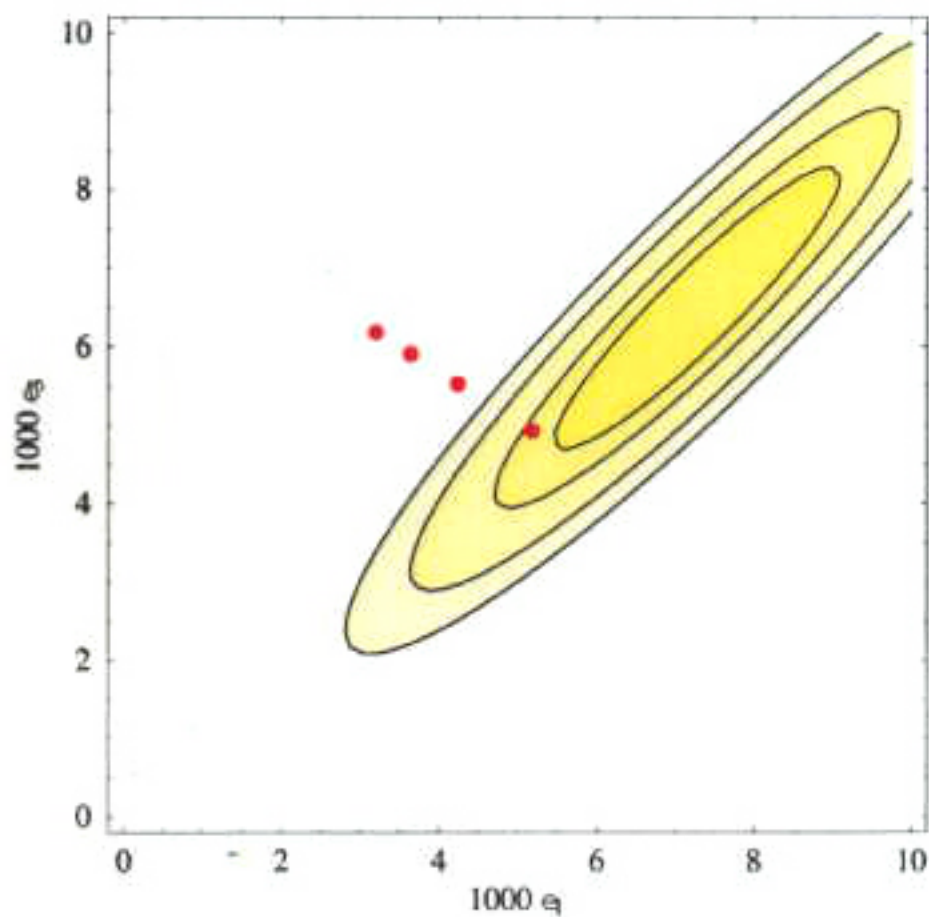
⇒ define 2 (g-2)-like observables
that include, among others, these
effects

$$\mu_e = \frac{e\hbar}{2m_e} 2 \left(1 + \frac{g-2}{2} \right) \leftarrow \overset{3}{\sim} + \dots$$

$$O_i = O_i^{\text{Born}} \left(1 + a_i \epsilon_1 + b_i \epsilon_3 \right)$$

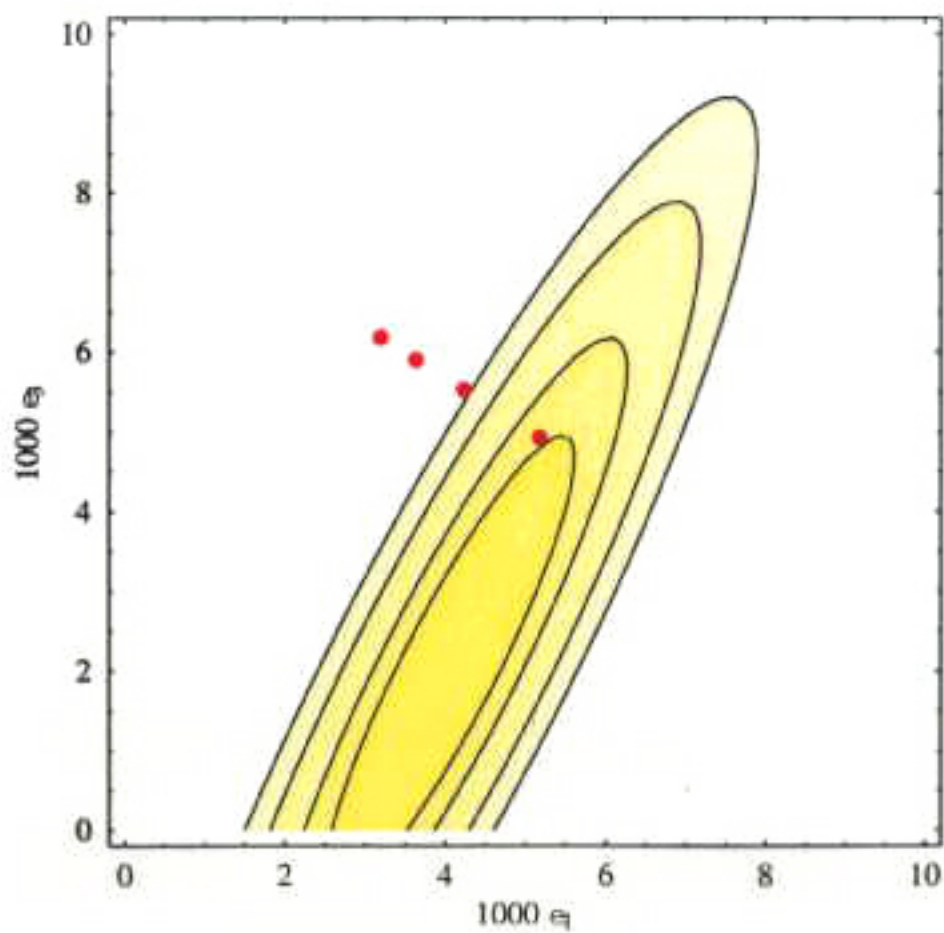


no GammaZ, NuTeV, QW



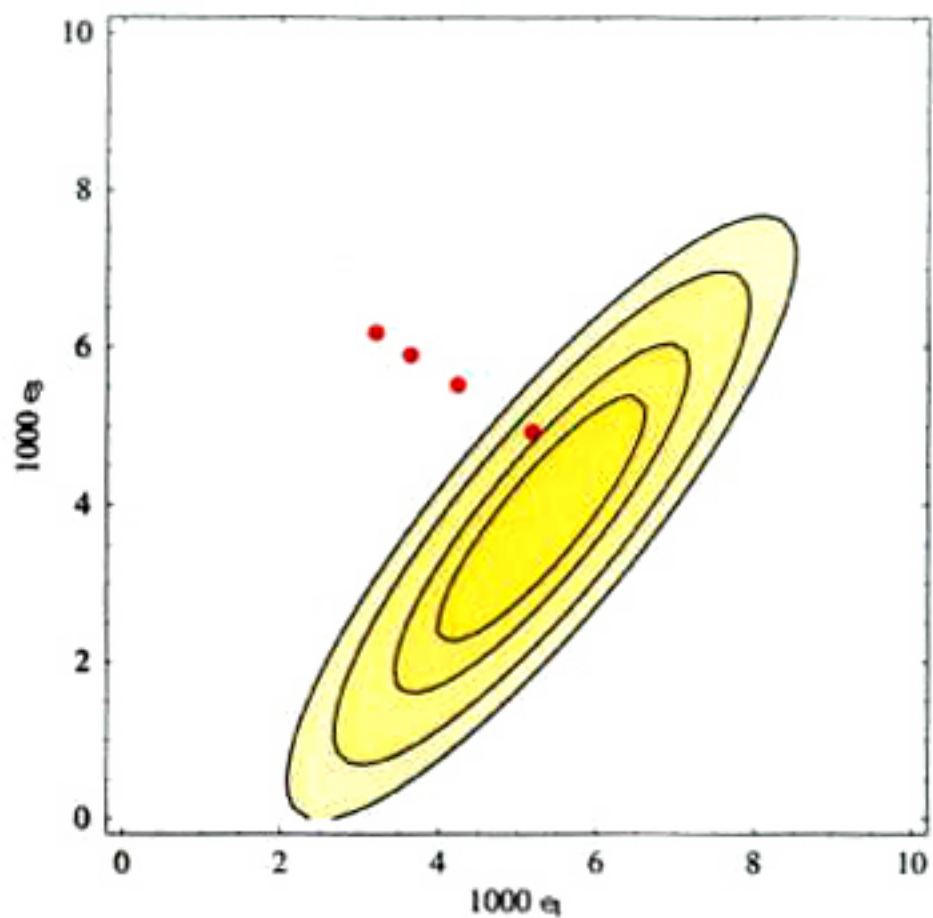
M_W
 A_b
 A_{opt}

no asimetrie



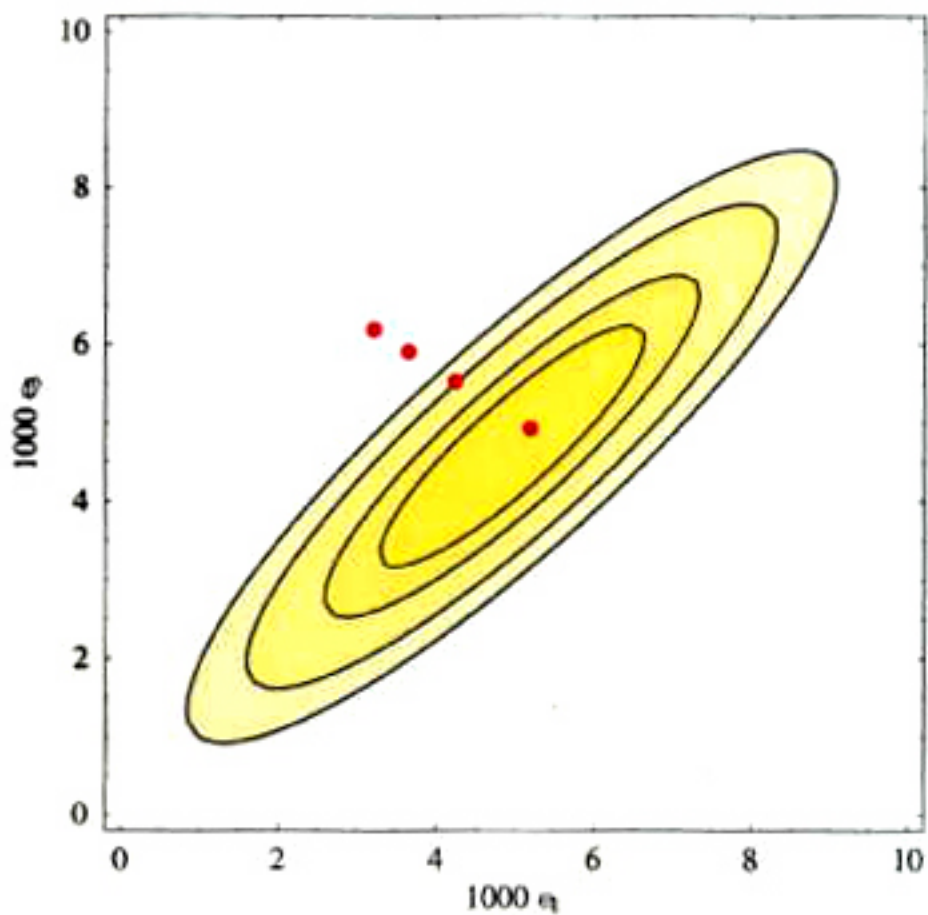
T_2
 M_W
 A_b

no NuTeV, A_b , A_c , QW



Γ_z
 M_W
 A_{left}

no MW, NuTeV, QW



Γ_z
 A_{left}
 A_b

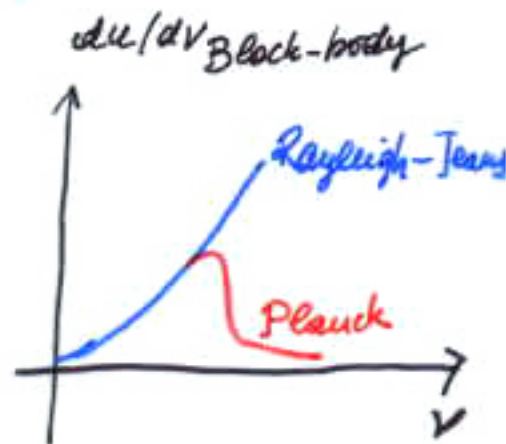
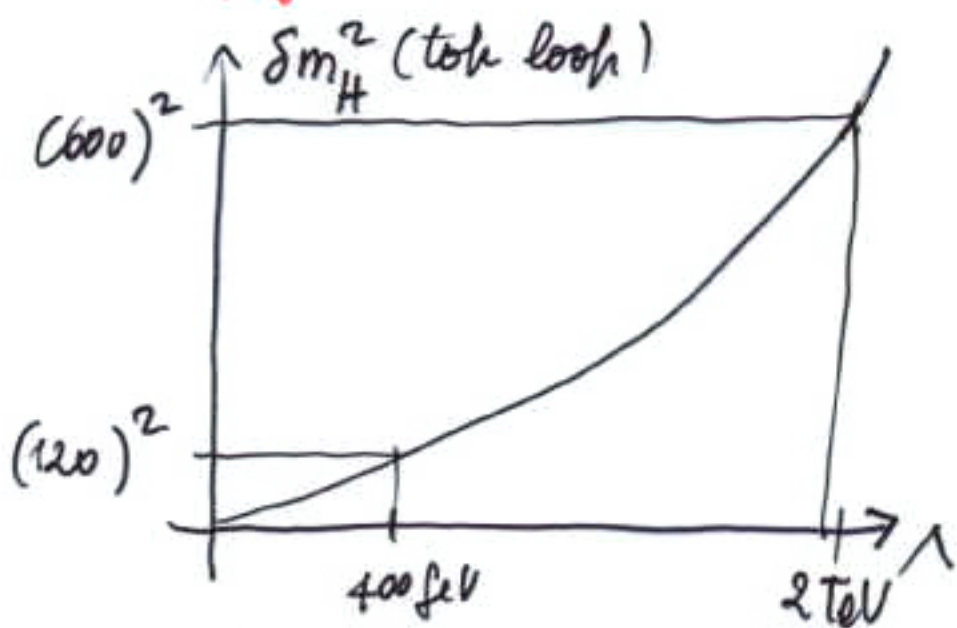
The "LEP paradox"

The "little hierarchy problem"

From $m_H \approx 100 \text{ GeV}$ and $m_t = 174 \pm 5 \text{ GeV}$

$$\text{Diagram: } \begin{array}{c} t \\ | \\ \text{---} \bigcirc \text{---} \\ | \\ h \end{array} \Rightarrow \delta m_H^2 = \frac{3}{\sqrt{2}\pi^2} C_F m_t^2 \Lambda^2 = (120 \text{ GeV})^2 \left(\frac{\Lambda}{400 \text{ GeV}} \right)^2$$

↑ the dominant loop eff. from known physics

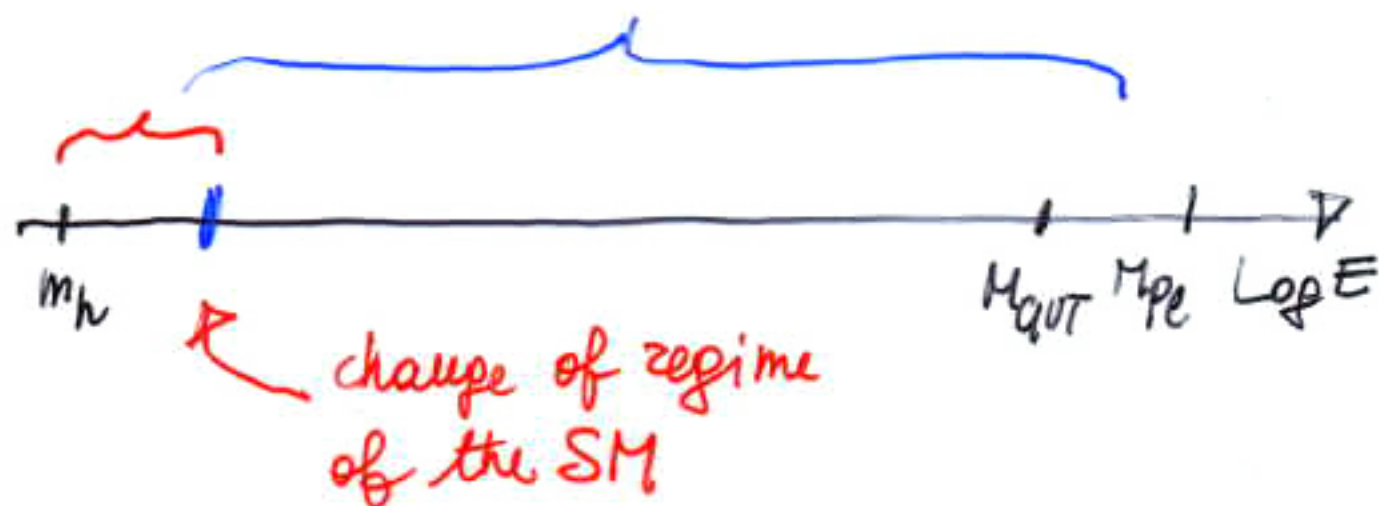


1. What cuts off the top loop?

2. Why no effect of such a low cut off not seen at LEP or anywhere else?

$$(m_H^2 = \delta m_H^2(\text{top loop}) - m_{H0}^2)$$

The "little hierarchy problem"



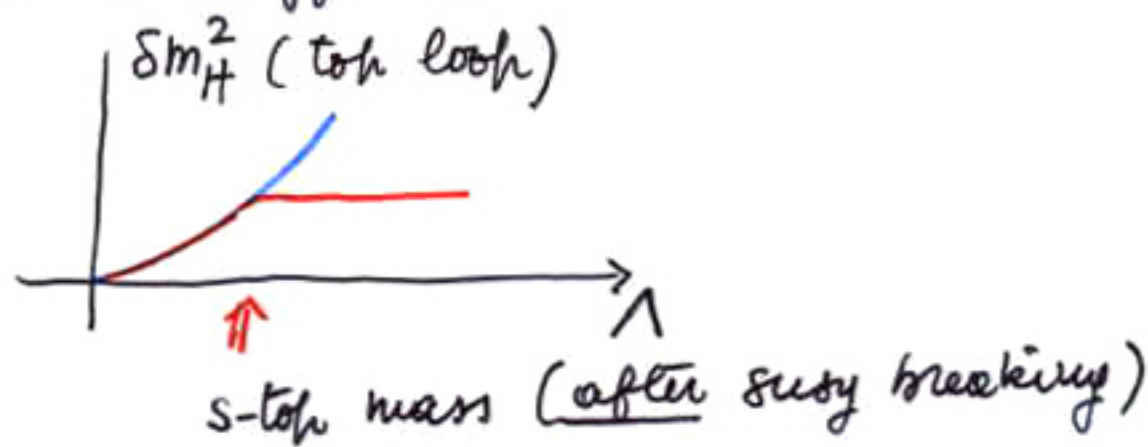
- Scale of Higgs compositeness
- Effective scale of supersymmetry breaking
- The inverse length of a compact extra dimension
- Breaking scale of a global symmetry leaving the Higgs as a pseudo-scalar
- ?

The supersymmetric solution

A further symmetry, which organizes every particle into doublets, degenerate in the exact symmetry limit

$$(V_1, \tilde{b}_{1/2}) \quad (\tilde{b}_{1/2}, \tilde{\varphi}_0) \quad (\tilde{\varphi}_0, \tilde{b}_{1/2})$$

makes to vanish the top loop correction to the Higgs mass



$EW/SB \Leftrightarrow$ susy breaking

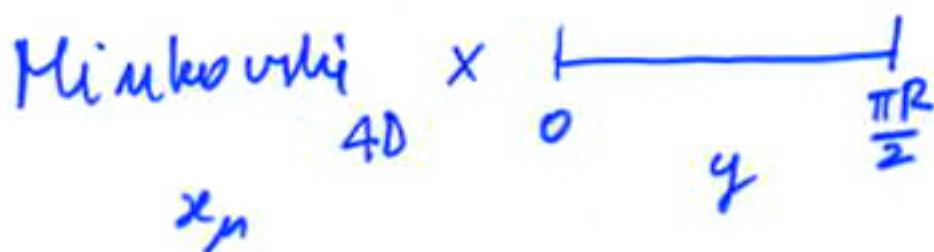
1. How is supersymmetry broken?
2. Where are the superpartners?

A proposal to solve the
"little hierarchy problem"

B, Hall, Nomura
...

Space-time =

$\Psi(x_\mu, y)$



with supersymmetry only broken by
by boundary conditions in the 5-th
dimension (à la Scherk-Schwarz) and
the e.w. symmetry broken radiatively
by the top Yukawa coupling (as usual)

Actual implementation

1. Give proper boundary conditions to $\psi(x, y)$ in the 5th dimension to retain SM degrees of freedom as the only massless particles before e.w. symm. breaking (possible in a unique way)
2. Calculate the Higgs potential ($V = \frac{g^2 + g'^2}{8} |\varphi|^4$ at tree level) and
Electroweak Symmetry Breaking

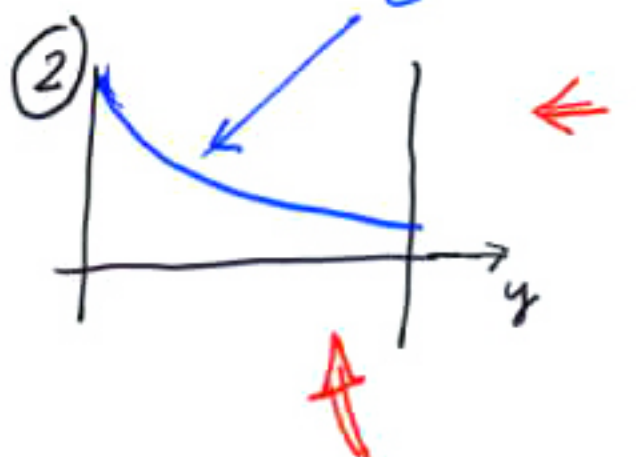
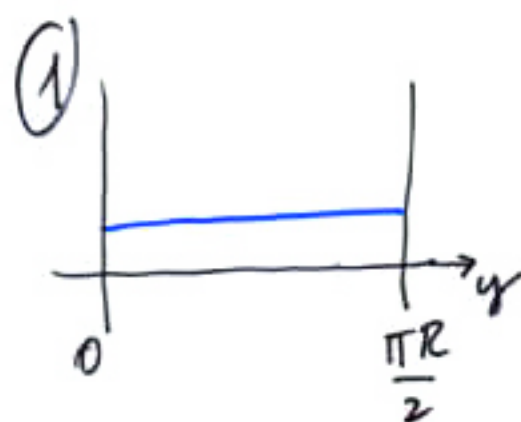
2 possible concrete realizations

1. The Constrained Standard Model

$$\lambda, \mu \Rightarrow 1/R \quad (\text{too low?})$$

2. The CSM with a Quasi-Localized Top

$$\lambda, \mu \Rightarrow 1/R, MR \quad \leftarrow \begin{array}{l} \text{localization} \\ \text{parameter} \end{array}$$



the top u.f. in y

Why?

1. $1/R$ as the only breaking parameter of supersymmetry

2. $h = h(x_\mu, y)_{N=2}$

$$+ \delta(y) h(x_\mu)_{N=1} + \delta(y - \frac{\pi R}{2}) h'(x_\mu)_{N=1'}$$

\Rightarrow enhanced calculability

3. one Higgs with $v \neq 0$ only, as in the SM and unlike the MSSM

$$V_{SM}(H) = \frac{1}{2}\mu^2 H^2 + \lambda H^4$$

$$\lambda \propto \log \Lambda, \quad \mu^2 \propto \Lambda^2$$

cut off - independent

$$V_{5D}(H; R, MR) = \frac{g^2 + g'^2}{8} H^4 + \delta V$$

$$\delta V^{(2\text{ loop})} = - \frac{0.001}{R^2} f(MR) H^2 + (\alpha \log^2 RH + \beta \log RH + \gamma) H^4$$

$f = O(1)$ for $MR = O(1)$

precisely calculable

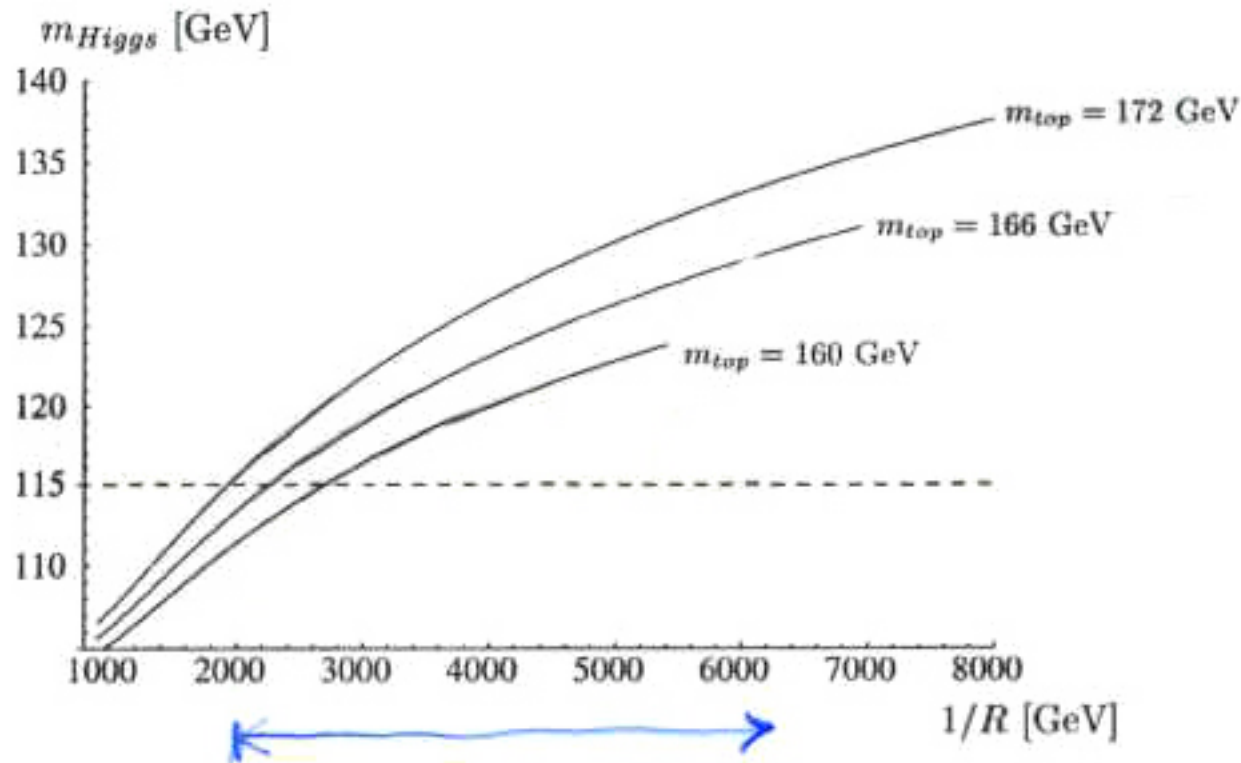
$$\Rightarrow R^{-1} \simeq 2 \div 6 \text{ TeV} \text{ dep. on } MR$$

$$m_H = m_H(R) \rightarrow \text{figure}$$

$$\Rightarrow m_{\tilde{t}_L} \simeq m_{\tilde{t}_R} \simeq m_{\tilde{b}_L} = \frac{0.25}{R} = 500 \div 1200 \text{ GeV}$$

$$m_{\tilde{g}} \simeq m_{\tilde{\chi}^\pm} \simeq m_{\tilde{\chi}} \simeq m_{\tilde{h}} = R^{-1}$$

B, Marandella, Papucci



$m_t(m_t)$

under refinement

$\Rightarrow \delta m_H / m_H \lesssim 3\%$ possible

Summary

- A - EWSB still an unsettled problem in particle physics, at the focus of exp. effort in present decade
- B - A "paradox" emerging from exp.s of past decade (mostly at LEP), motivating a fresh look at the EWSB problem [The "little hierarchy problem"]
- C - Proposed solution: supersymmetry only broken by boundary conditions on a 5th dimension: Allows an accurate calculation of $V_{\text{sym. break.}} = V(H; R; MR)$