LHC commissioning

(early) Beyond Standard Model (BSM) physics

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LHC commissioning and (early) BSM physics

... a most exciting adventure!

- Where do we start from?
  The possible BSM roads
- Status of LHC, machine and detectors, and their commissioning

- Re-discovering the Standard Model
  BSM explorations
  - ∗ Supersymmetry

  - ∗ Other scenarios
- Towards a model-independent approach

LECTURE 1 A

WHAT DO WE KNOW?

OVERVIEW OF BSM PHYSICS

WHERE DO WE START FROM?

- **Constraints from the Earth:**
  LEP/SLC, Tevatron, HERA, (lower energies)

- **Constraints from the sky**
  Dark matter, others

What did we learn from LEP, etc, about:

Standard Model

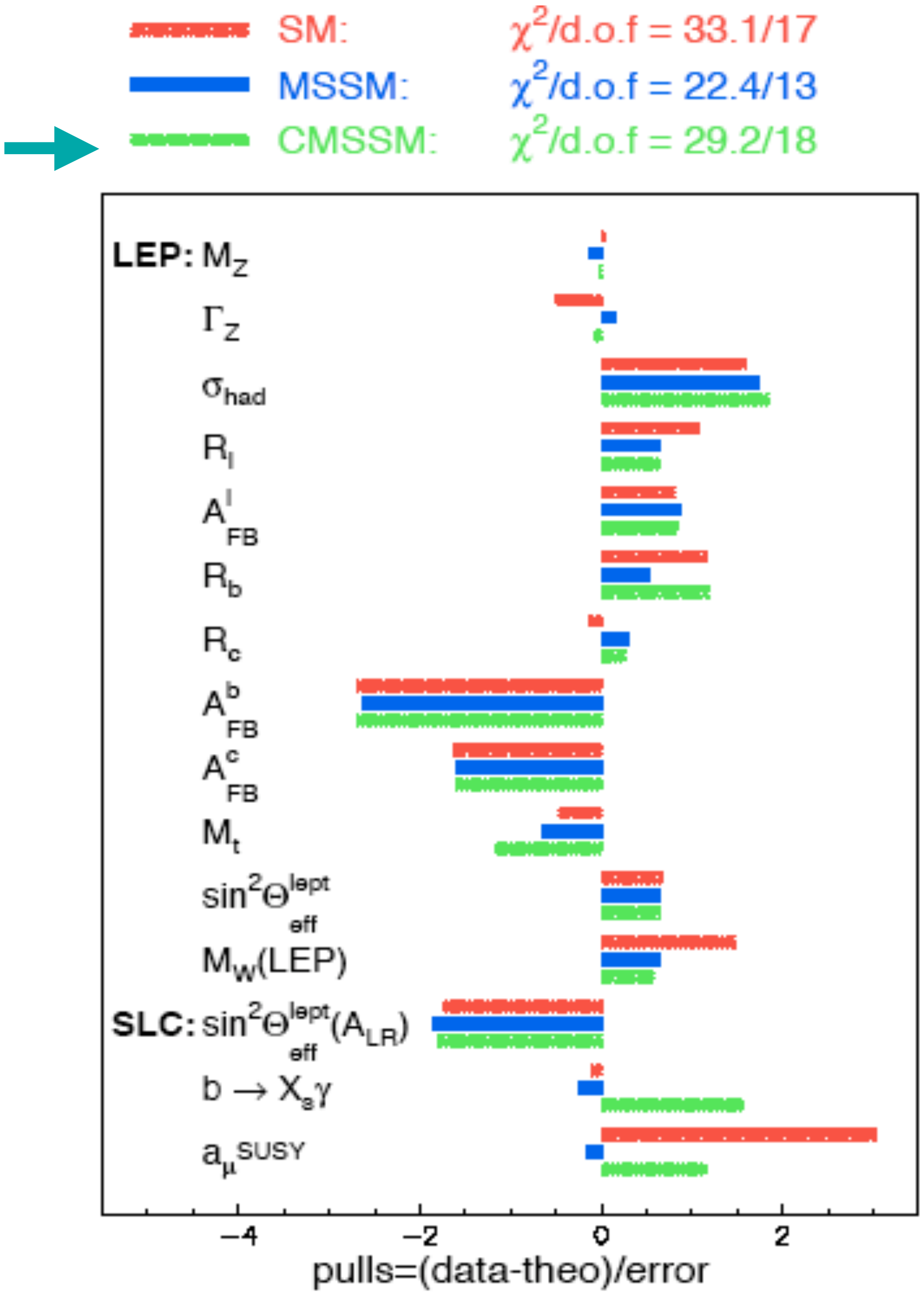
Higgs

MSSM (Minimal Supersymmetric SM)

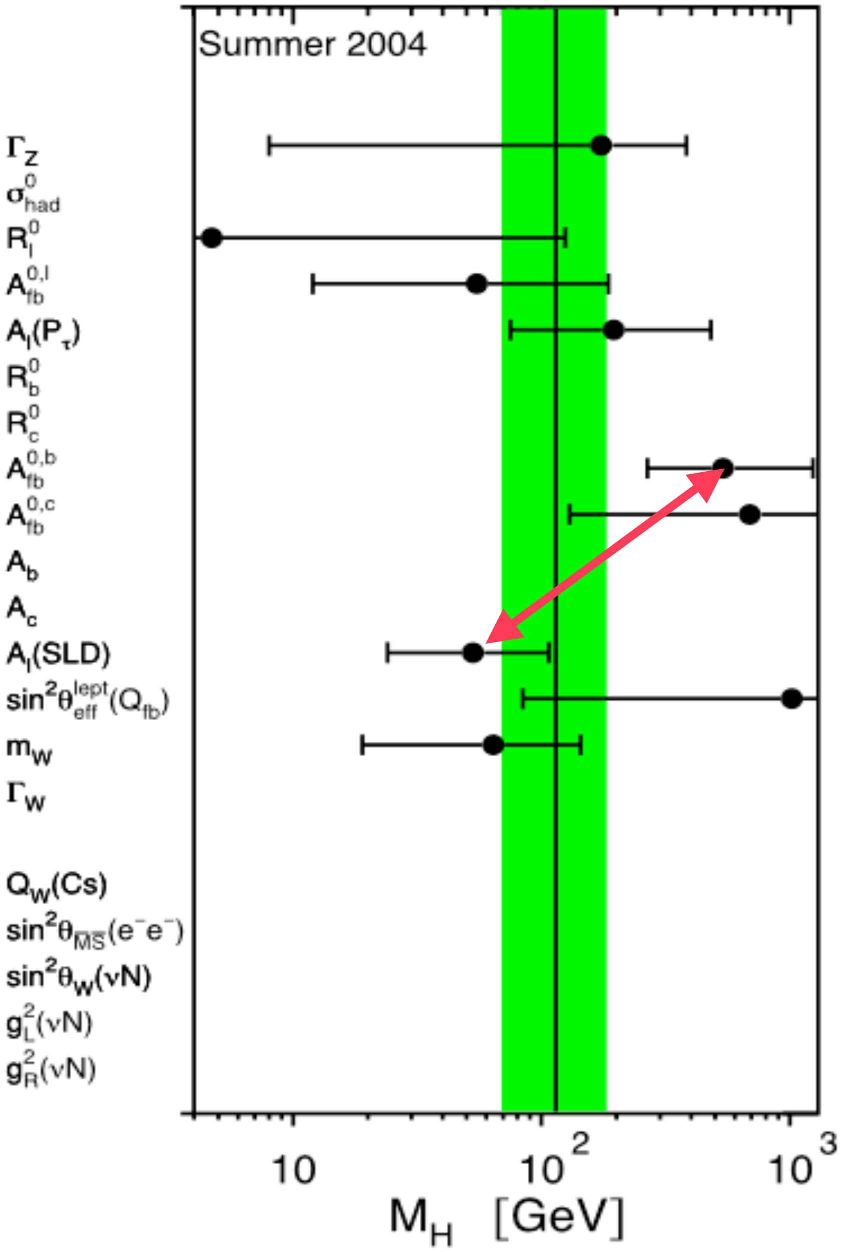
0511088 is hep-ph/ unless stated otherwise
0710.3022 is arXiv

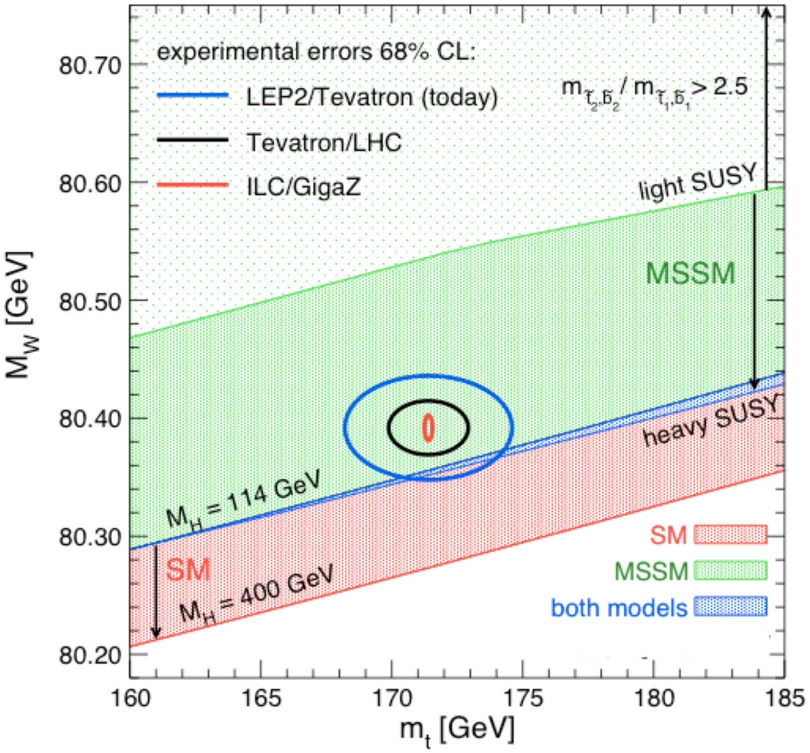
de Boer et al

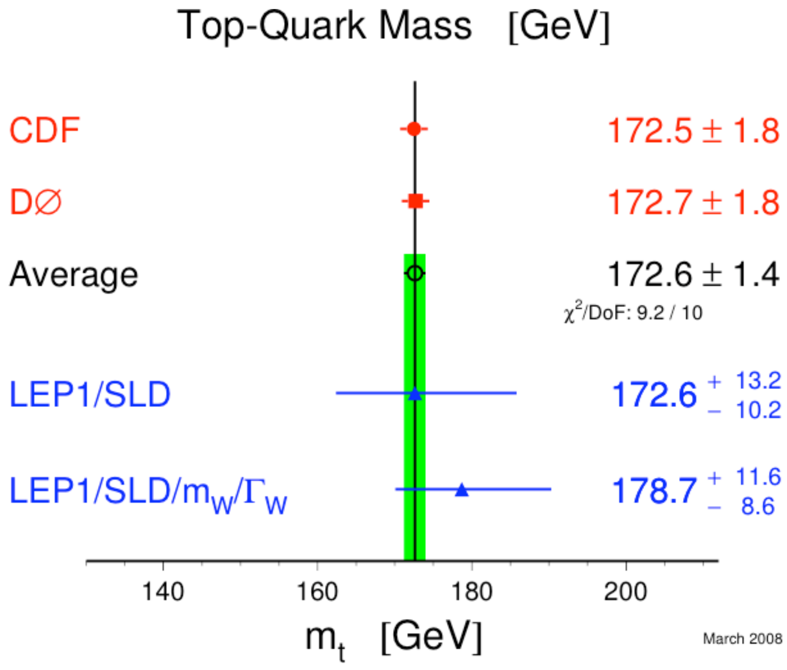
Pulls

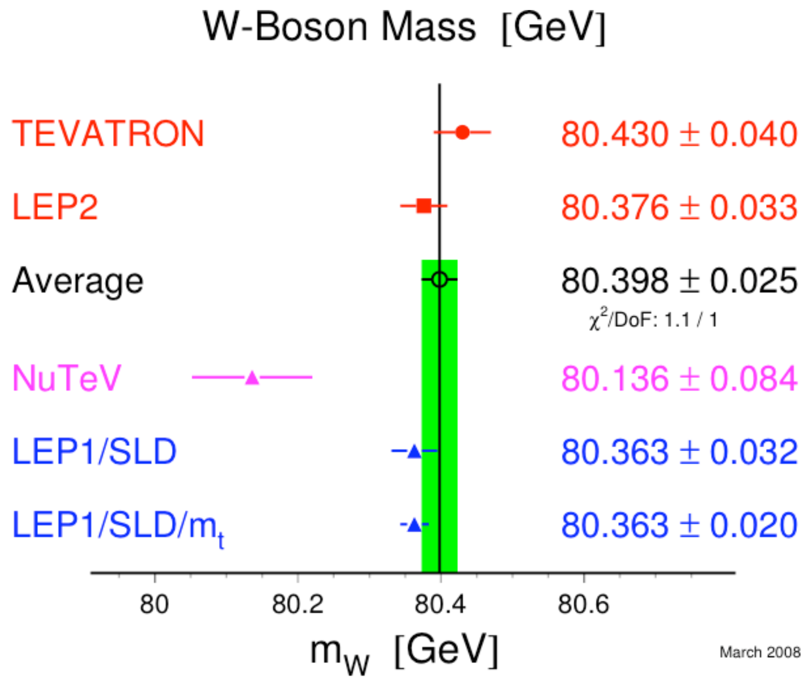


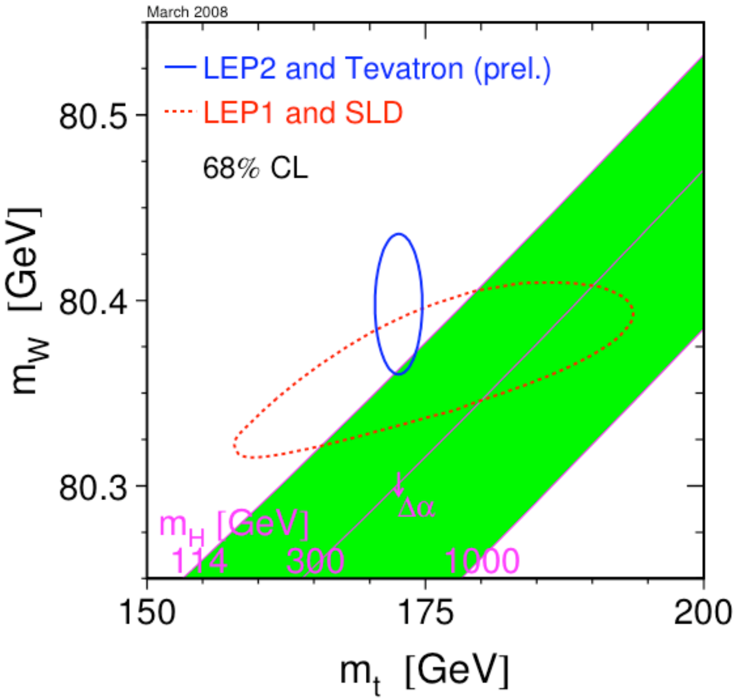
M_H from various observables

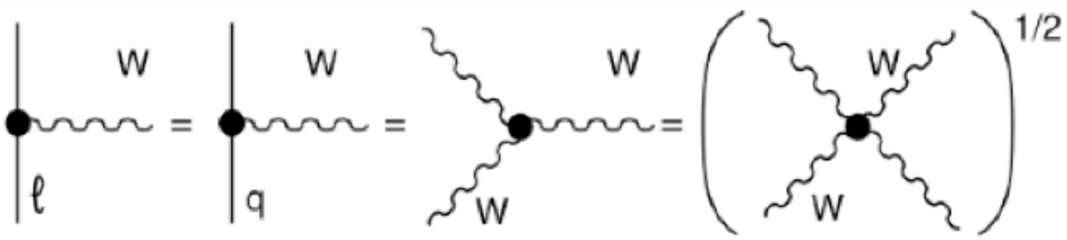



experimental errors 68% CL:
LEP2/Tevatron (today)
Tevatron/LHC
ILC/GigaZ
$m_{\tilde{t}_2,\tilde{b}_2} / m_{\tilde{t}_1,\tilde{b}_1} > 2.5$
light SUSY
MSSM
heavy SUSY
$M_H = 114$ GeV
$M_H = 400$ GeV
SM
SM
MSSM
both models
80.70
80.60
80.50
80.40
80.30
80.20
M_W [GeV]
160
165
170
175
180
185
m_t [GeV]


Top-Quark Mass [GeV]
CDF
172.5 ± 1.8
DØ
172.7 ± 1.8
Average
172.6 ± 1.4
χ^2/DoF: 9.2 / 10
LEP1/SLD
172.6 $^{+13.2}_{-10.2}$
LEP1/SLD/m_W/Γ_W
178.7 $^{+11.6}_{-8.6}$
140
160
180
200
m_t [GeV]
March 2008


W-Boson Mass [GeV]
TEVATRON
80.430 ± 0.040
LEP2
80.376 ± 0.033
Average
80.398 ± 0.025
χ^2/DoF: 1.1 / 1
NuTeV
80.136 ± 0.084
LEP1/SLD
80.363 ± 0.032
LEP1/SLD/m_t
80.363 ± 0.020
80
80.2
80.4
80.6
m_W [GeV]
March 2008


March 2008
LEP2 and Tevatron (prel.)
LEP1 and SLD
68% CL
80.5
80.4
80.3
m_W [GeV]
$\Delta\alpha$
m_H [GeV]
114
300
1000
150
175
200
m_t [GeV]



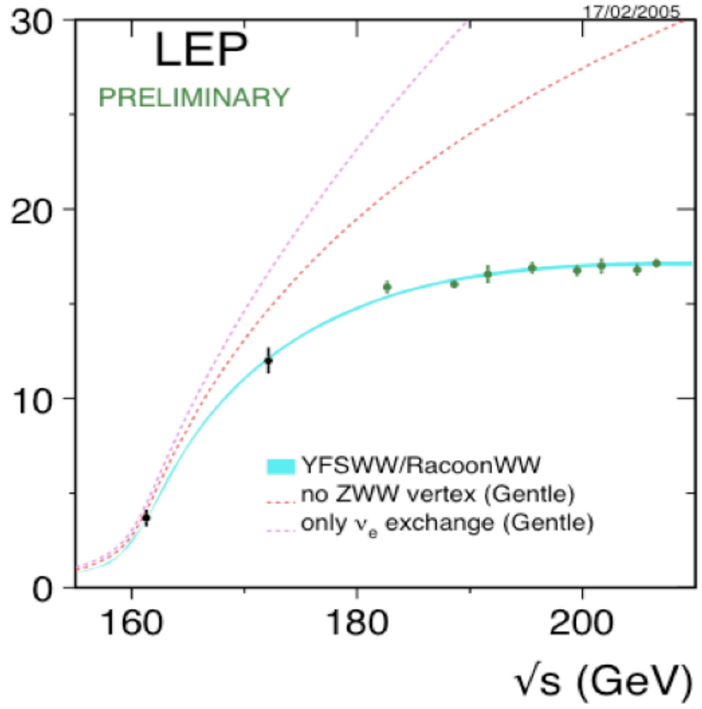
gauge boson couplings are SM-like

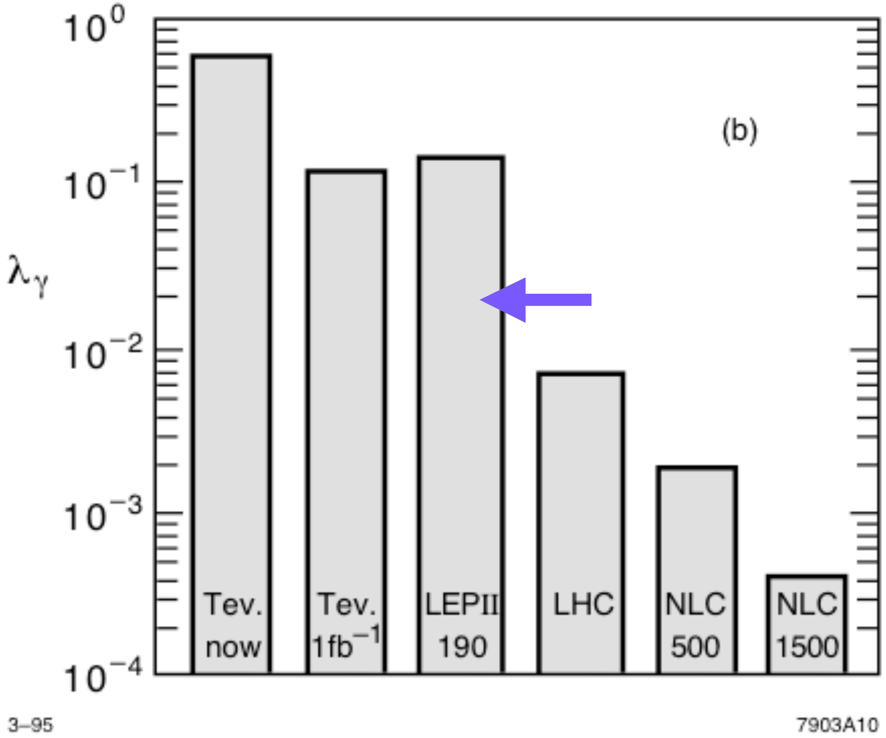
W triple gauge couplings measured at ±2-4%

$$\kappa_\gamma = 0.984 \begin{smallmatrix}+0.042\\-0.047\end{smallmatrix}$$

$$\lambda_\gamma = -0.016 \begin{smallmatrix}+0.021\\-0.023\end{smallmatrix}$$

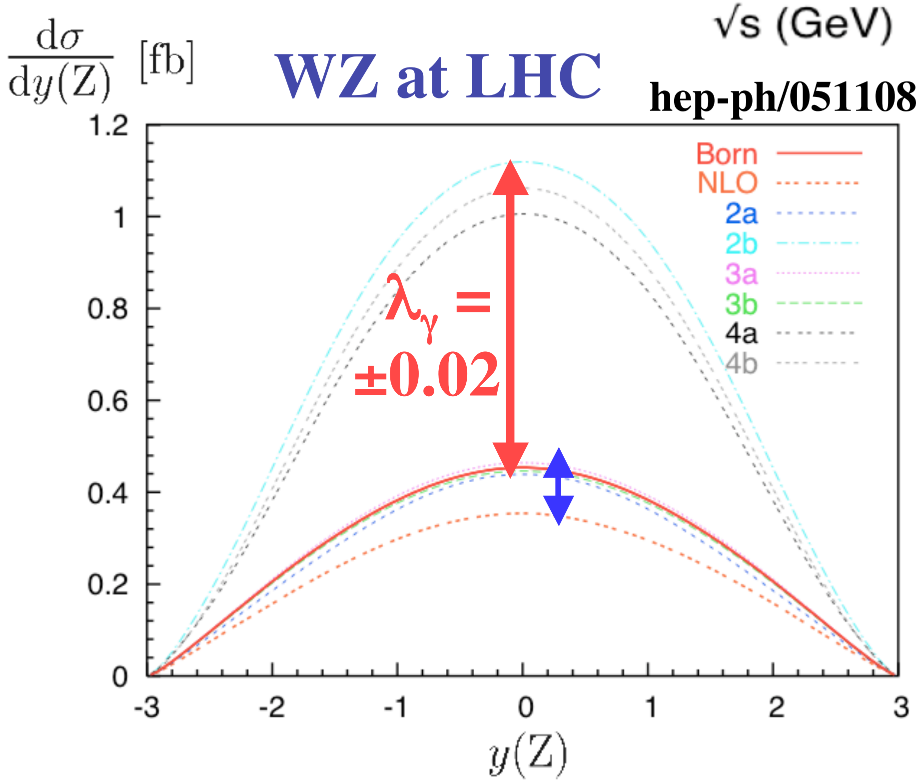
$$g_1^Z = 0.991 \begin{smallmatrix}+0.022\\-0.021\end{smallmatrix}$$



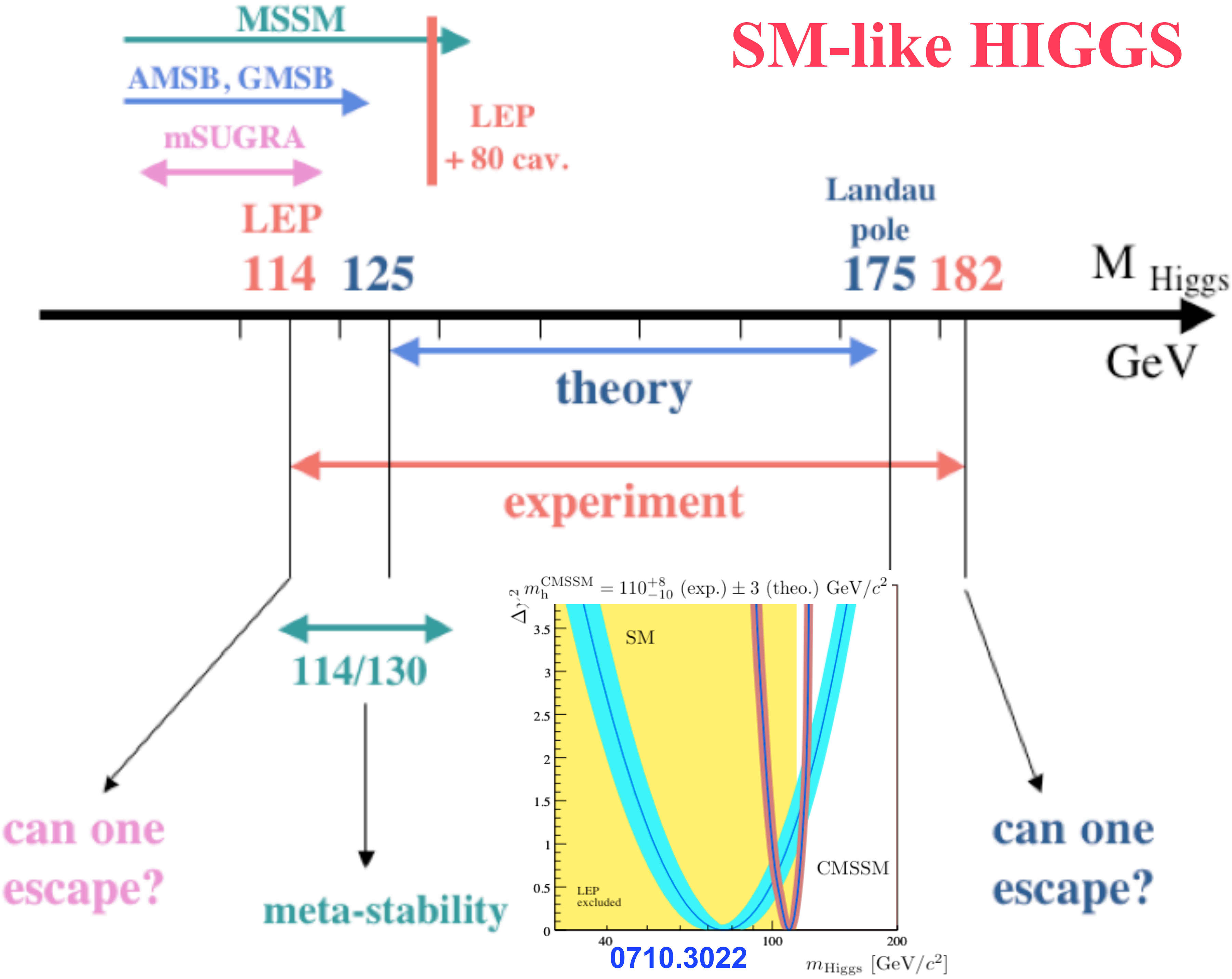


WZ at LHC

hep-ph/0511088



SM-like HIGGS



MSSM

AMSB, GMSB

mSUGRA

LEP

LEP + 80 cav.

Landau pole

114 125 175 182

M Higgs GeV

theory

experiment

114/130

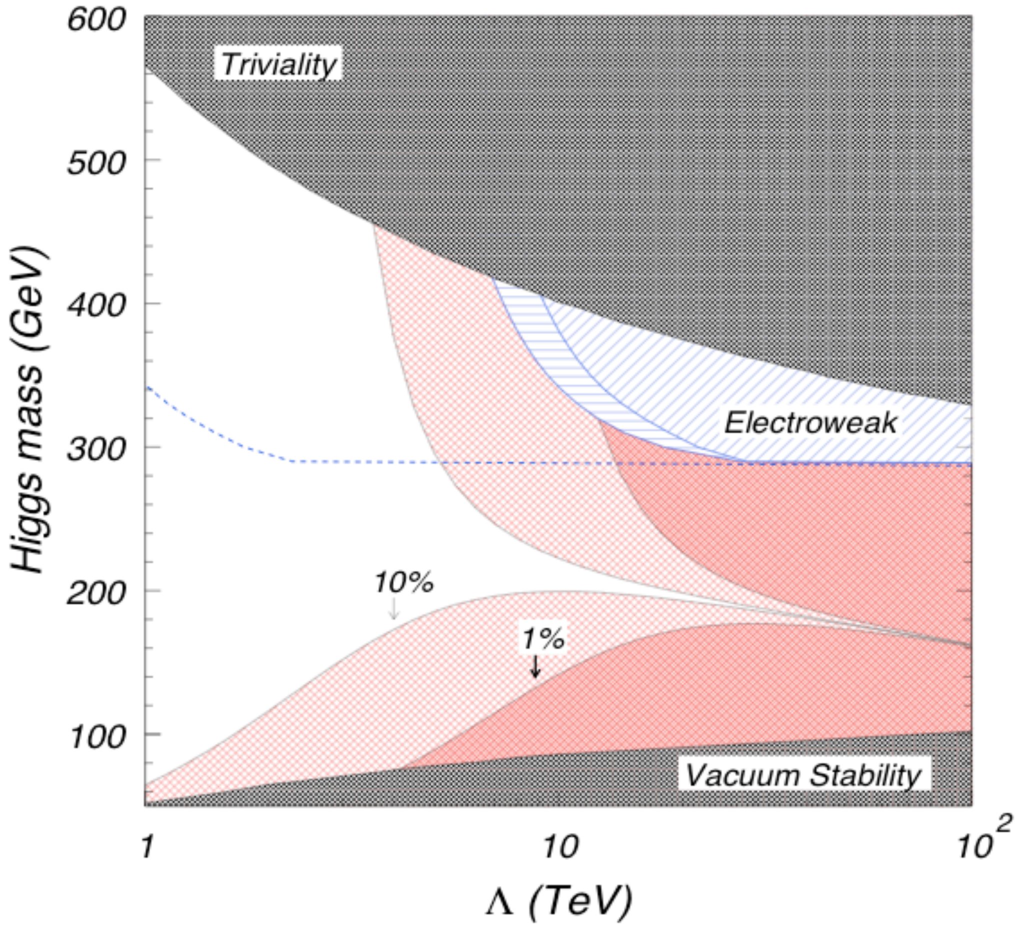
can one escape?

meta-stability

can one escape?

0710.3022

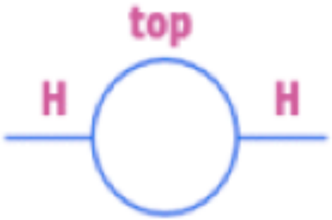
Kolda-Murayama



up to where SM is valid

$$M_H^2 = M_0^2 + \delta M_H^2$$

SM Higgs: fine tuning increasing with the cut-off



⇒

$$\delta M_H^2(\text{top}) \approx G_F M_{top}^2 \Lambda^2 \approx (0.3\,\Lambda)^2$$

$\Lambda = 5$ TeV

$\delta M_H^2(\text{top}) =$

$2.25\ \text{TeV}^2$

Other limits on Higgs bosons (GeV)

MSSM, small m_A	$m_h > 92.8$
	$m_A > 93.4$
charged	76.6 –78.6
doubly charged	95.5
fermiophobic	109.7
invisible	114.2
flavour independent	112.9

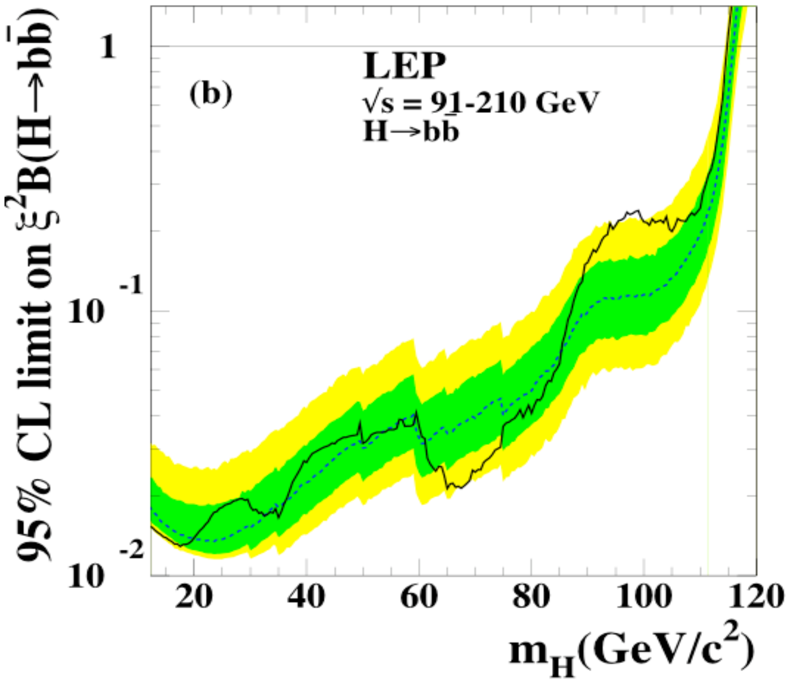
But some searches missing (or not ADLO)

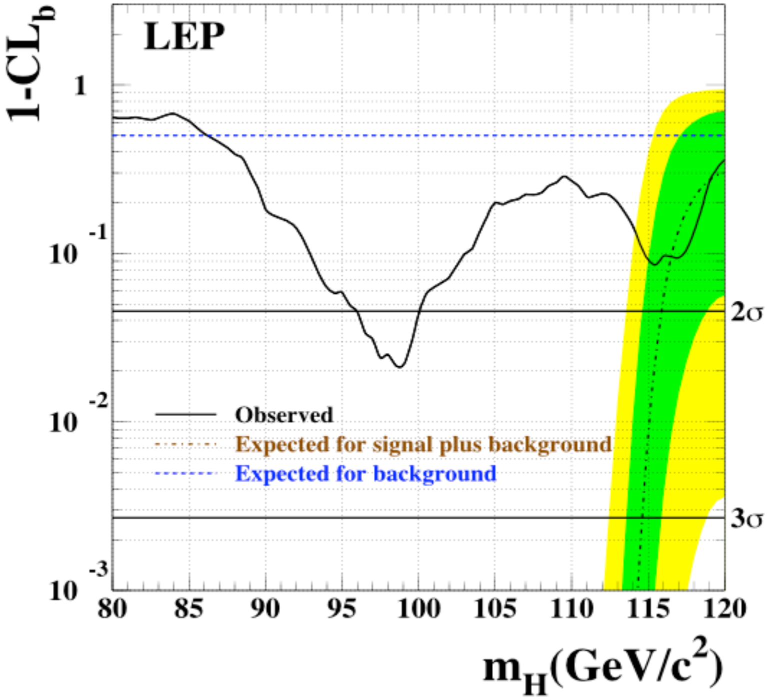
ex. $h \rightarrow aa \rightarrow 4\tau$

possible in NMSSM, even MSSM?

h would be the “97 GeV” bump,

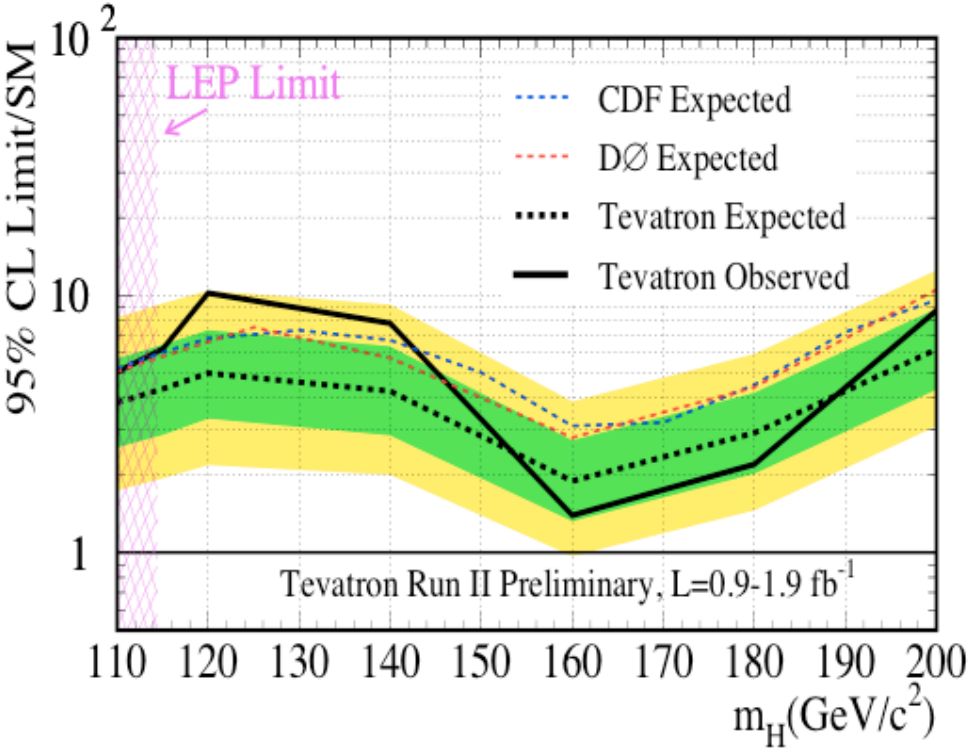
the next boson would be the “115 GeV”



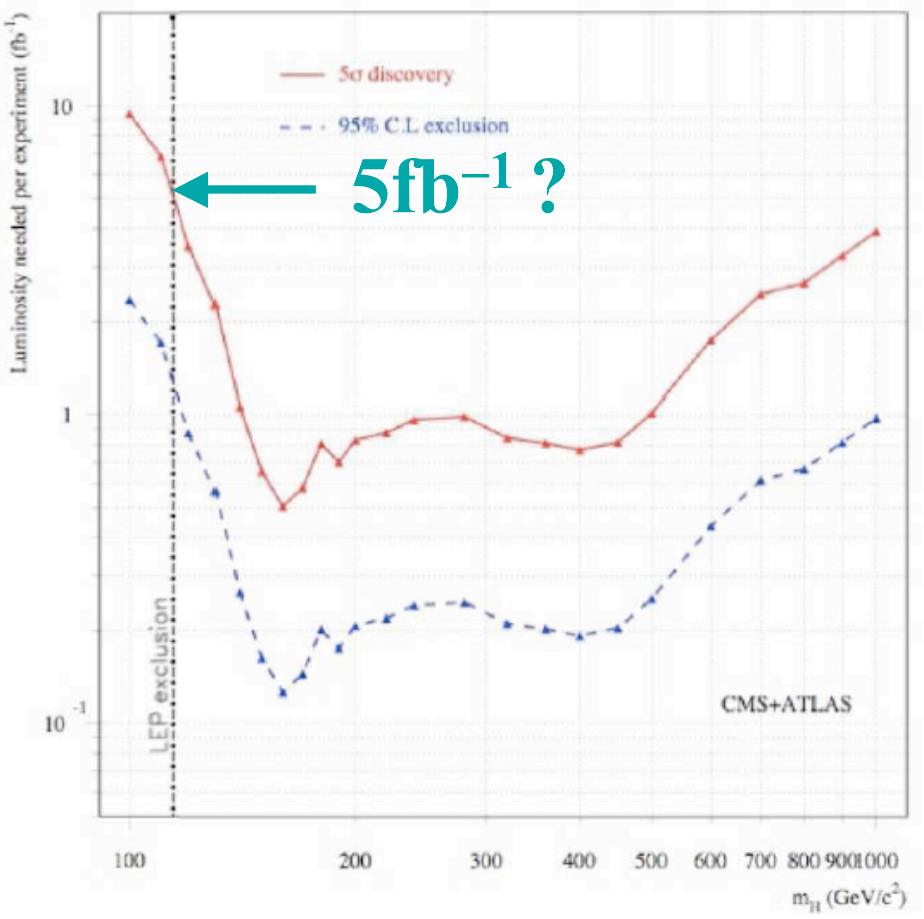


Next?

Tevatron 0805.1248



LHC 0804.4401

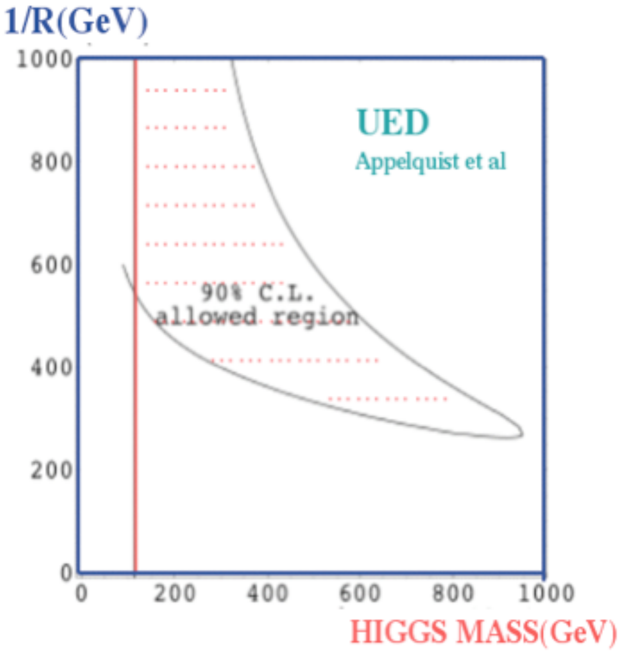


5fb^{-1} ?

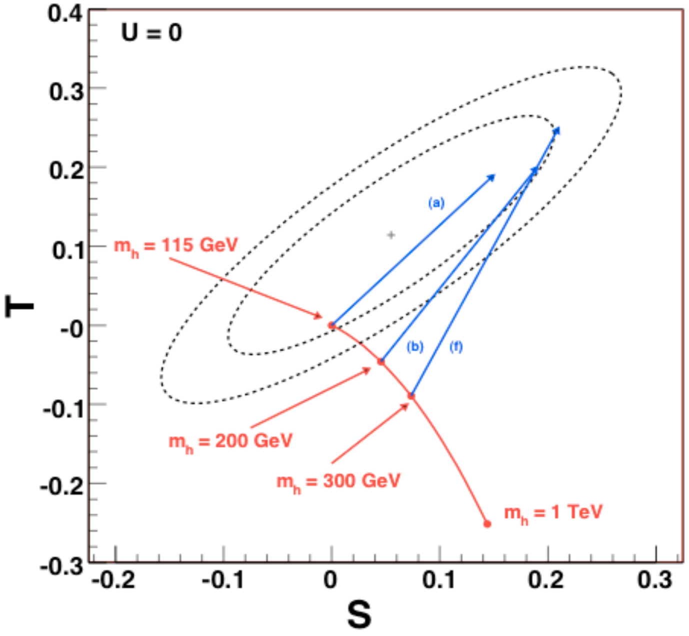
SM ⟷ Higgsless

in-between: Higgs and something else (KK, ..) share their role

If the Higgs is more elusive, is the "something else" more visible?

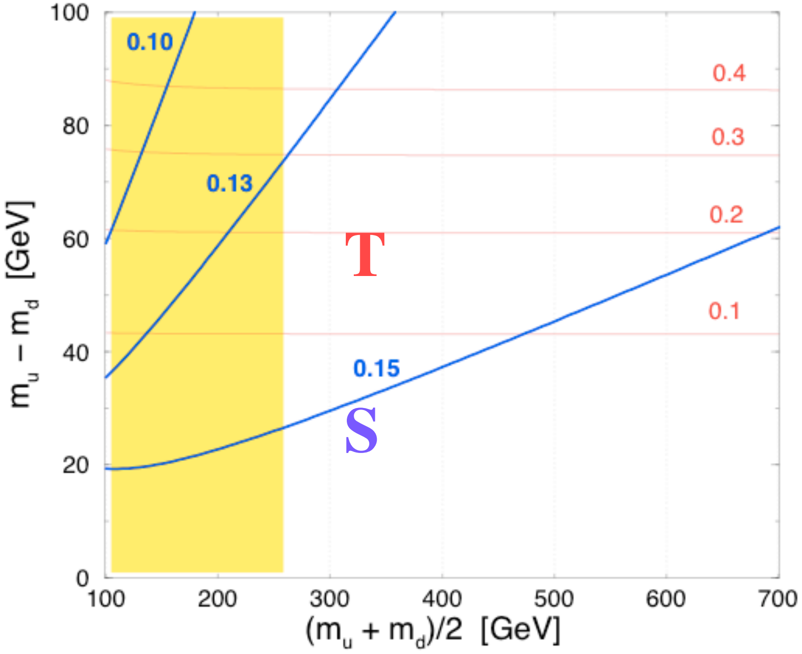


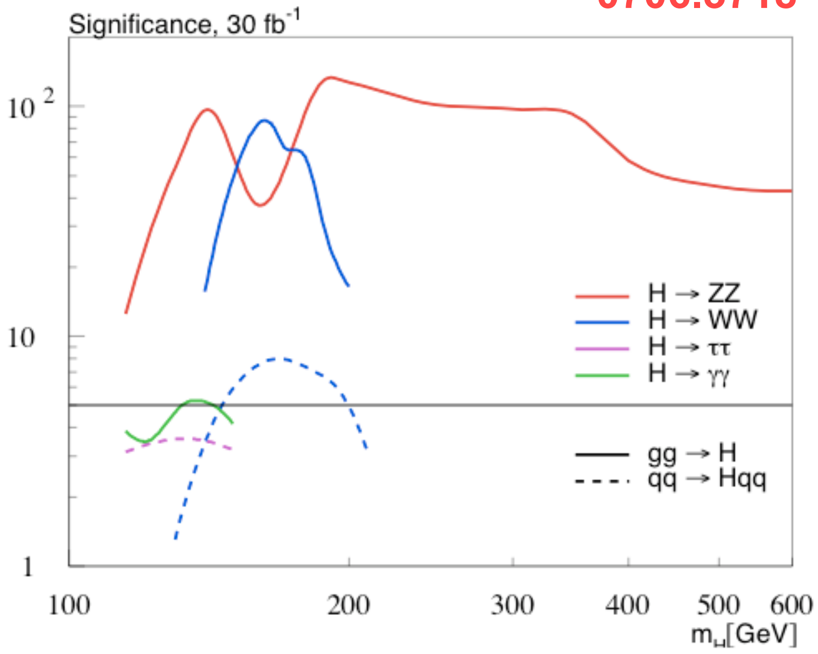
many possibilities of conspirations with new physics, allowing for a heavier Higgs (Peskin-Wells)



funny example: 4th generation, with heavy ν

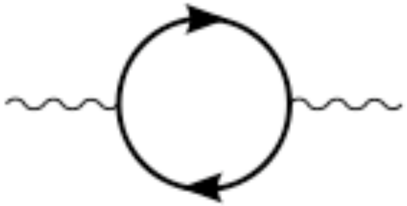
0706.3718





- S,T (ε_i) global variables
- What was “felt” at LEP
- The ρ parameter
- The b coupling

To parameterize potential new physics contributions to e.w. radiative corrections one needs 4 vacuum polarization functions: self-energies of γ, Z, W and γ-Z mixing induced by loop diagrams



expand in powers of q^2/M^2

$$\Pi_{\gamma\gamma}(q^2) = q^2\Pi'_{\gamma\gamma}(0) + \ldots$$
$$\Pi_{Z\gamma}(q^2) = q^2\Pi'_{Z\gamma}(0) + \ldots$$
$$\Pi_{ZZ}(q^2) = \Pi_{ZZ}(0) + q^2\Pi'_{ZZ}(0) + \ldots$$
$$\Pi_{WW}(q^2) = \Pi_{WW}(0) + q^2\Pi'_{WW}(0) + \ldots$$

define S, T, U

measures the difference between the number of LH and RH doublets carrying weak isospin

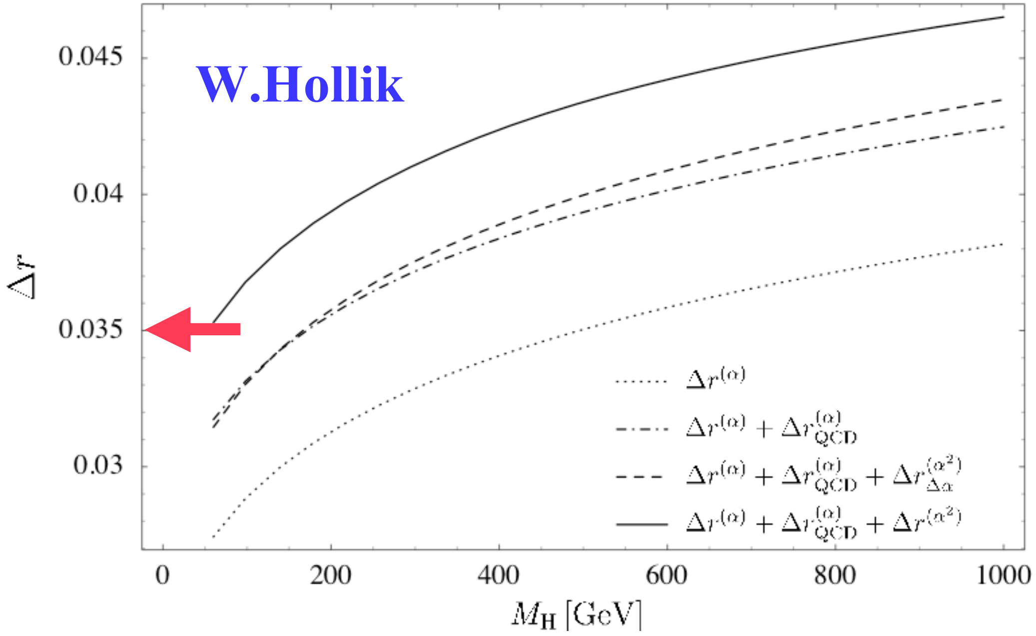
$$\alpha S = 4s_w^2c_w^2\left[\Pi'_{ZZ}(0) - \frac{c_w^2 - s_w^2}{s_w c_w}\Pi'_{Z\gamma}(0) - \Pi'_{\gamma\gamma}(0)\right]$$

measures isospin violation

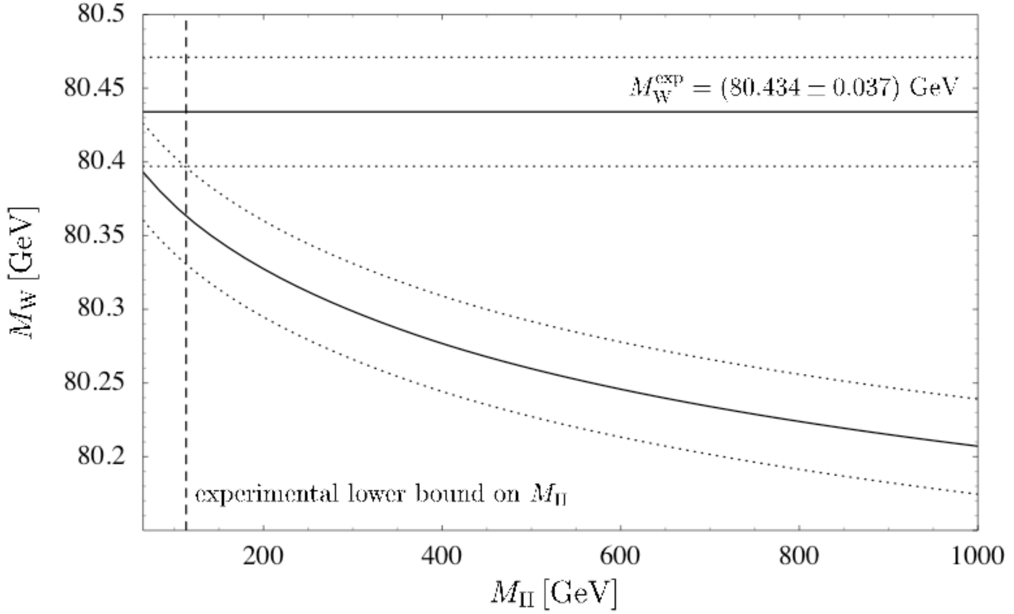
$$\alpha T = \frac{\Pi_{WW}(0)}{M_W^2} - \frac{\Pi_{ZZ}(0)}{M_Z^2}$$

both sensitive to the Higgs mass

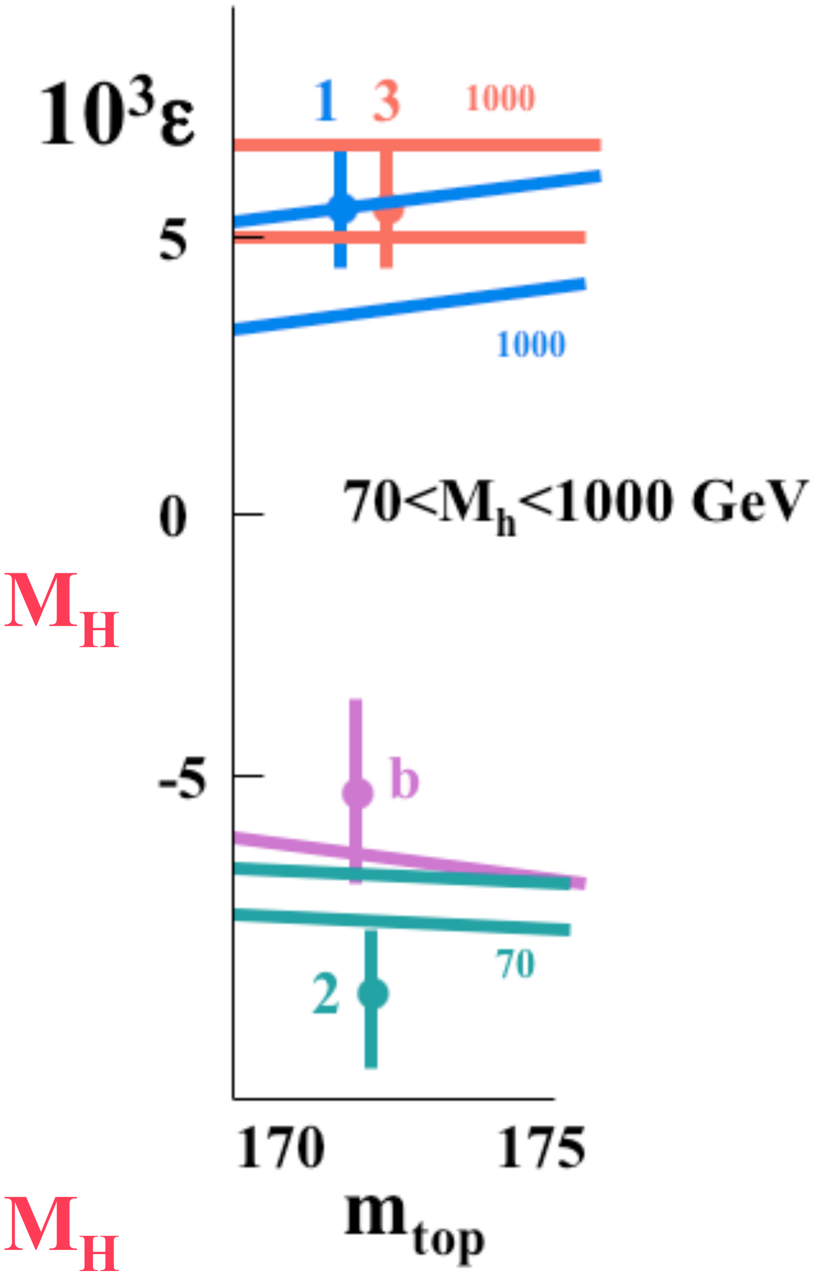
T (~ ε_1) : heavy degenerate fermions do not contribute
S (~ ε_3) : heavy degenerate fermions contribute



M_H



M_H



"Thus the statement that the precision data favors a light Higgs, as opposed to no Higgs at all, relies upon some theoretical baggage." Joe Lykken

The ρ parameter

$$\rho = \frac{M_W^2}{\cos^2\theta_W M_Z^2}$$

$$\rho = \frac{g^2}{8\cos^2\theta_W M_Z^2} \bigg/ \frac{g^2}{8M_W^2}$$

relative intensity of the
neutral et charged
effective Lagrangians

weak isospin

$$\rho = \frac{\sum_i \left[T_i(T_i+1) - (T_{3\,i})^2\right] v_i^2}{2\sum_i (T_{3\,i})^2 v_i^2}$$

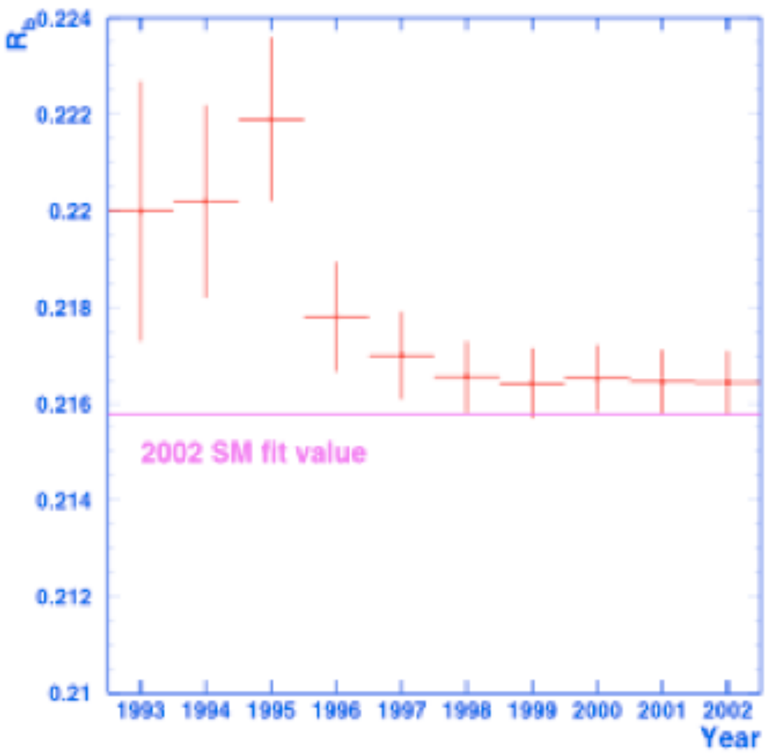
several Higgs
multiplets

z component

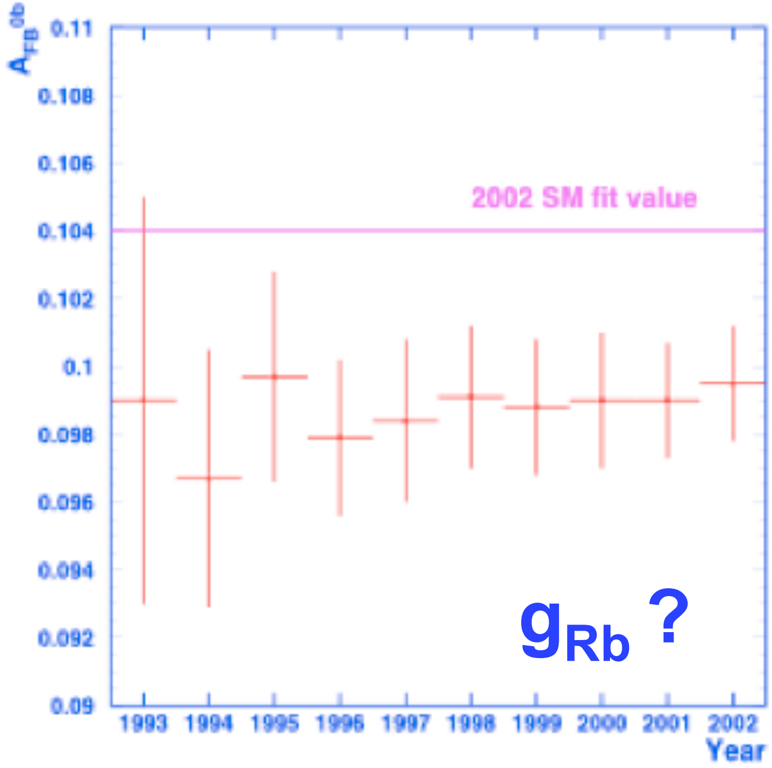
good test of the isospin
structure, also sensitive to
radiative corrections

only Higgs singlets + doublets
→ ρ = 1

an anomaly that faded away: R_b



an anomaly that stayed: $A_{FB}{}^b$



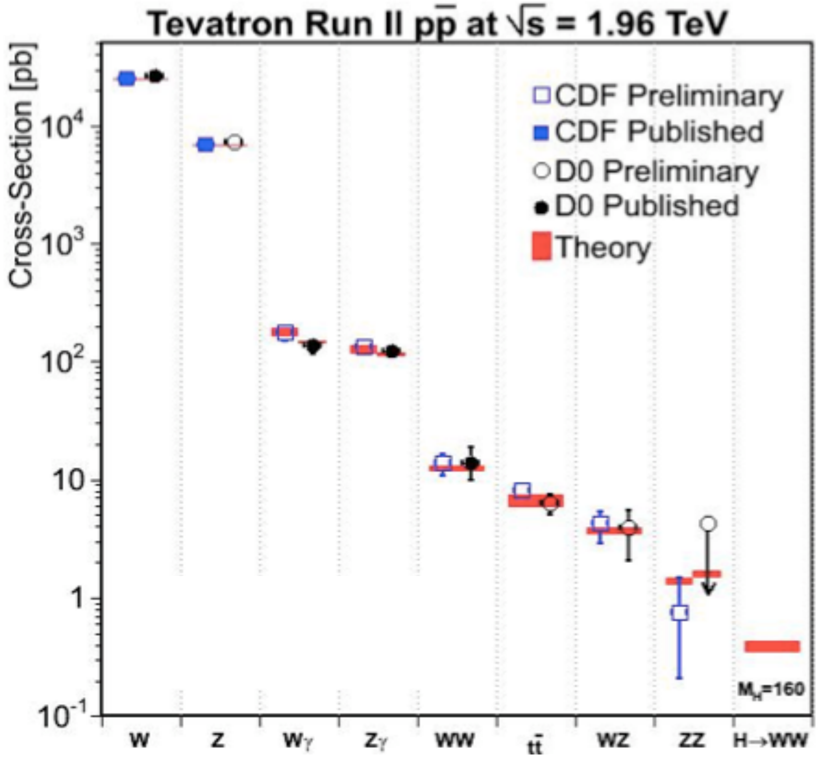
g_{Rb} ?

$\Delta\rho \leq 2\ 10^{-3}$ → custodial symmetry

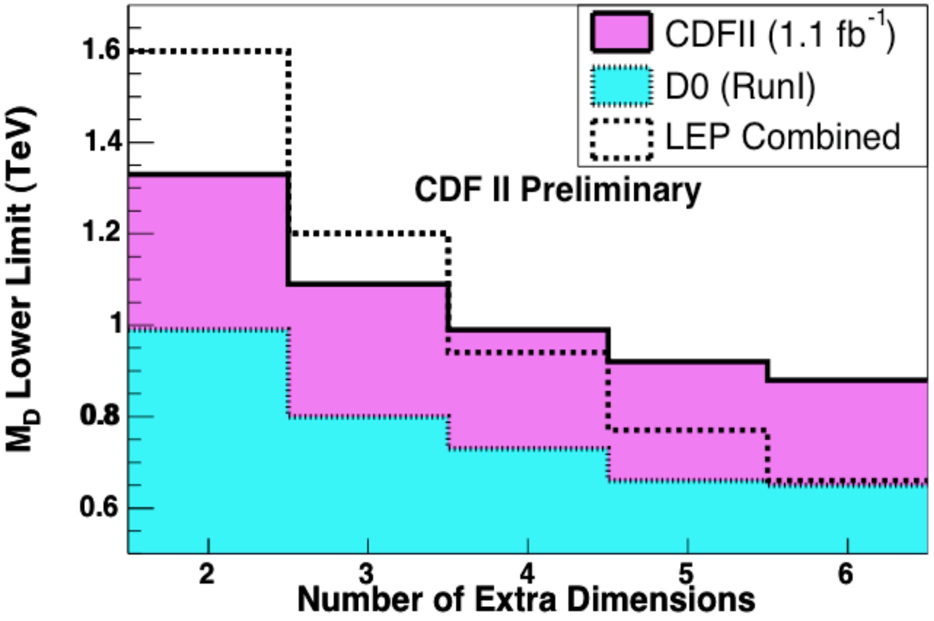
$\delta g_{Lb} / |g_{Lb}| \leq 0.25\%$ → custodial parity

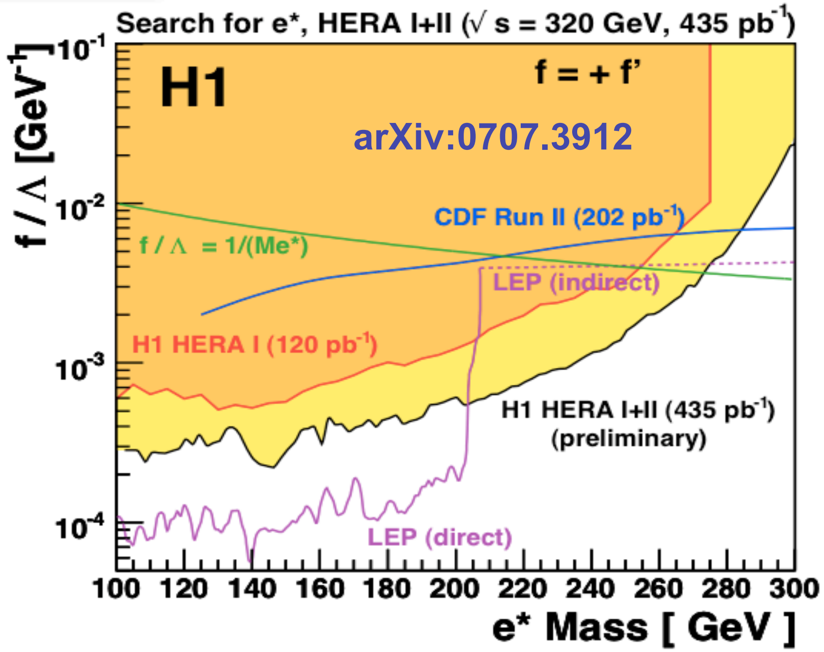
- 0605341: $O(4) \rightarrow O(3)$, equivalent to $SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$
  together with $L \rightarrow R$ (P_{LR})

allows to protect g_{Lb} and to modify g_{Rb}, does not protect g_{Top}

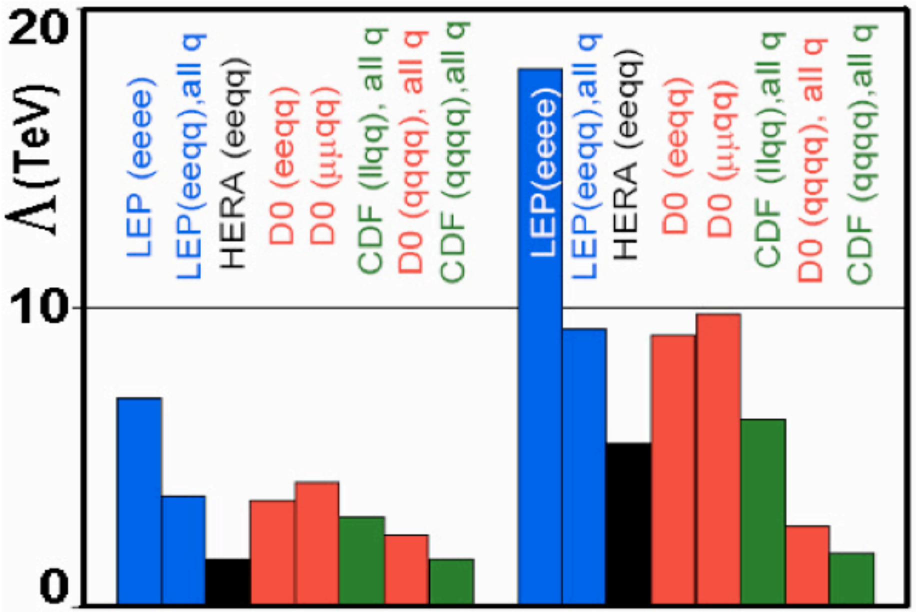


hep-ex/0610087



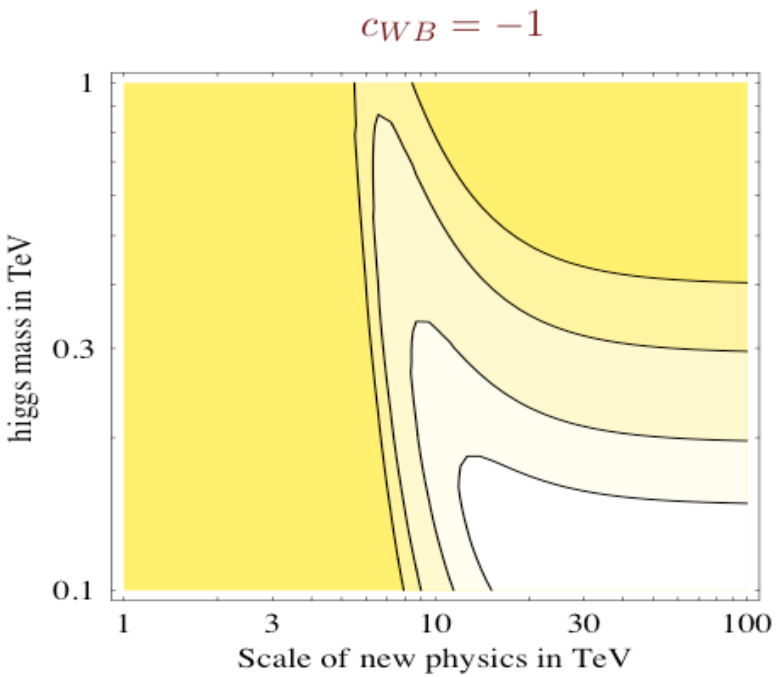


Compositeness, hep-ex/0512006



LEP paradox hep-ph/0007265

$$\mathcal{L}_{\rm eff}(E<\Lambda)=\mathcal{L}_{\rm SM}+\sum_{i,p}\frac{c_i}{\Lambda^p}\mathcal{O}_i^{(4+p)}$$



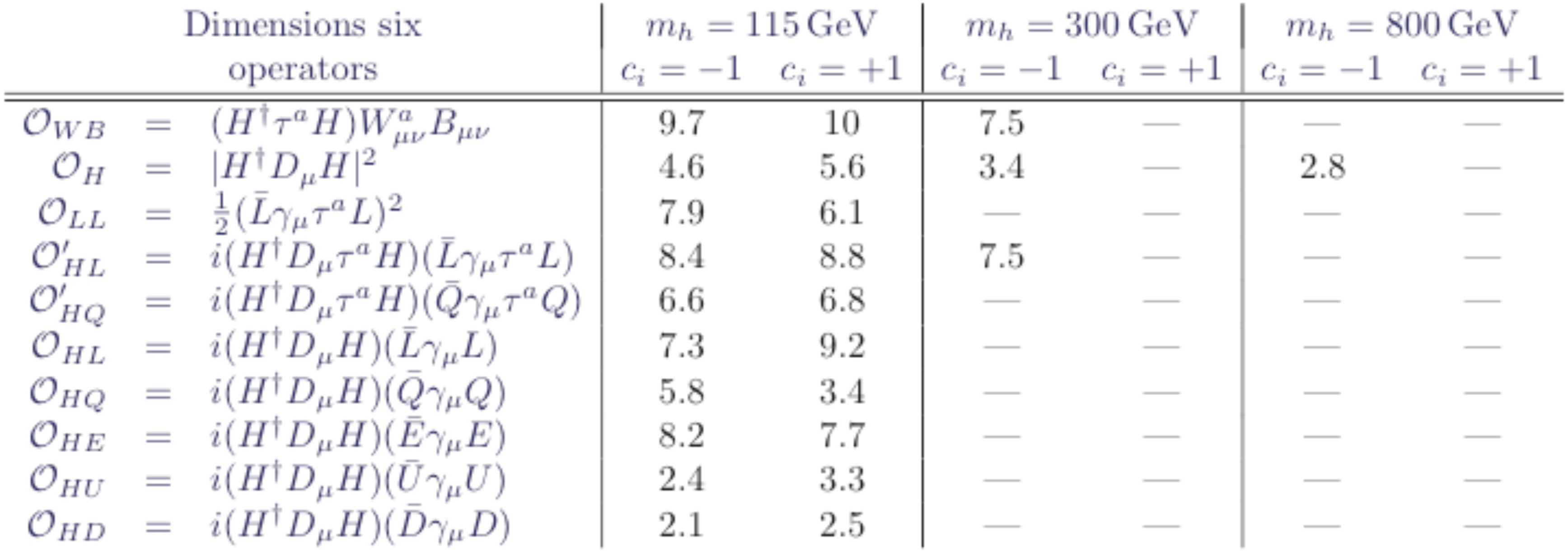
LEP2 sensitive to 4-f operators normalized as $\frac{4\pi}{\Lambda^2}(\bar{e}\gamma_\mu e)(\bar{f}\gamma_\mu f)$ up to $\Lambda\approx\sqrt{\frac{sN^{1/2}}{\alpha}}\approx 10\,\text{TeV}$

sparticles generate such operators at 1-loop

with coefficients $4\pi/\Lambda^2 \sim g^4/(4\pi m_{\rm SUSY})^2$

→ $m_{\rm SUSY}\gtrsim g^2\Lambda/(4\pi)^{3/2} \approx 100\,\text{GeV}$

does not apply to SUSY



Dimensions six operators			$m_h=115\,\text{GeV}$		$m_h=300\,\text{GeV}$		$m_h=800\,\text{GeV}$	
			$c_i=-1$	$c_i=+1$	$c_i=-1$	$c_i=+1$	$c_i=-1$	$c_i=+1$
$\mathcal{O}_{WB}$	$=$	$(H^\dagger\tau^a H)W^a_{\mu\nu}B_{\mu\nu}$	9.7	10	7.5	—	—	—
$\mathcal{O}_{H}$	$=$	$\lvert H^\dagger D_\mu H\rvert^2$	4.6	5.6	3.4	—	2.8	—
$\mathcal{O}_{LL}$	$=$	$\frac{1}{2}(\bar{L}\gamma_\mu\tau^a L)^2$	7.9	6.1	—	—	—	—
$\mathcal{O}'_{HL}$	$=$	$i(H^\dagger D_\mu\tau^a H)(\bar{L}\gamma_\mu\tau^a L)$	8.4	8.8	7.5	—	—	—
$\mathcal{O}'_{HQ}$	$=$	$i(H^\dagger D_\mu\tau^a H)(\bar{Q}\gamma_\mu\tau^a Q)$	6.6	6.8	—	—	—	—
$\mathcal{O}_{HL}$	$=$	$i(H^\dagger D_\mu H)(\bar{L}\gamma_\mu L)$	7.3	9.2	—	—	—	—
$\mathcal{O}_{HQ}$	$=$	$i(H^\dagger D_\mu H)(\bar{Q}\gamma_\mu Q)$	5.8	3.4	—	—	—	—
$\mathcal{O}_{HE}$	$=$	$i(H^\dagger D_\mu H)(\bar{E}\gamma_\mu E)$	8.2	7.7	—	—	—	—
$\mathcal{O}_{HU}$	$=$	$i(H^\dagger D_\mu H)(\bar{U}\gamma_\mu U)$	2.4	3.3	—	—	—	—
$\mathcal{O}_{HD}$	$=$	$i(H^\dagger D_\mu H)(\bar{D}\gamma_\mu D)$	2.1	2.5	—	—	—	—

Challenge: push Λ up to ~ 10 TeV while keeping the Higgs light

How to keep it light?
Higgs as a pseudo-Goldstone boson
Gauge invariance: gauge-Higgs unification

How to satisfy the electroweak constraints?
Custodial symmetry
Custodial parity

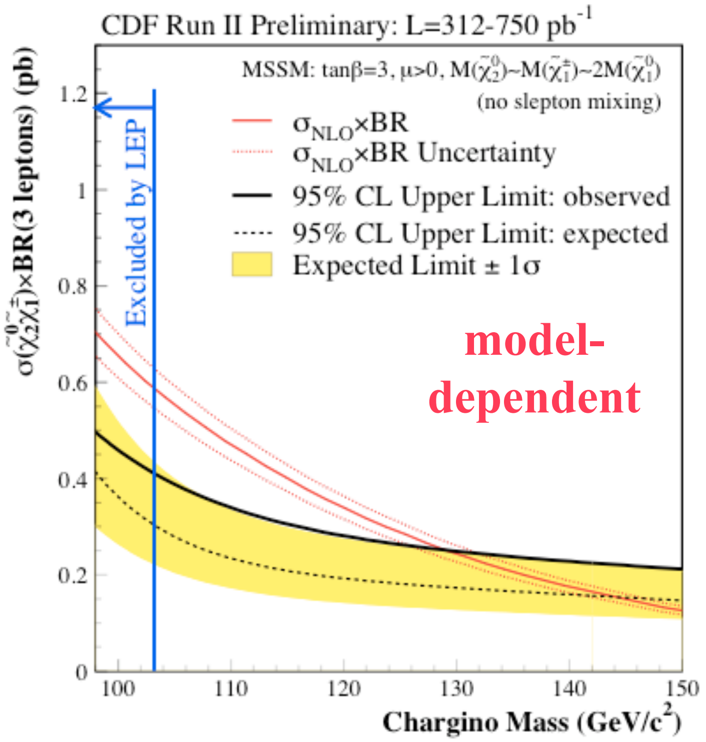
SUSY after LEP2, etc: it hides well...

LEP2 electroweak measurements have cancelled the slight preference of LEP1 measurements for light SUSY (g-2?)

hep-ph/0502095

Many final state topologies have been explored

Many lower mass limits set, usually close to LEP beam energy



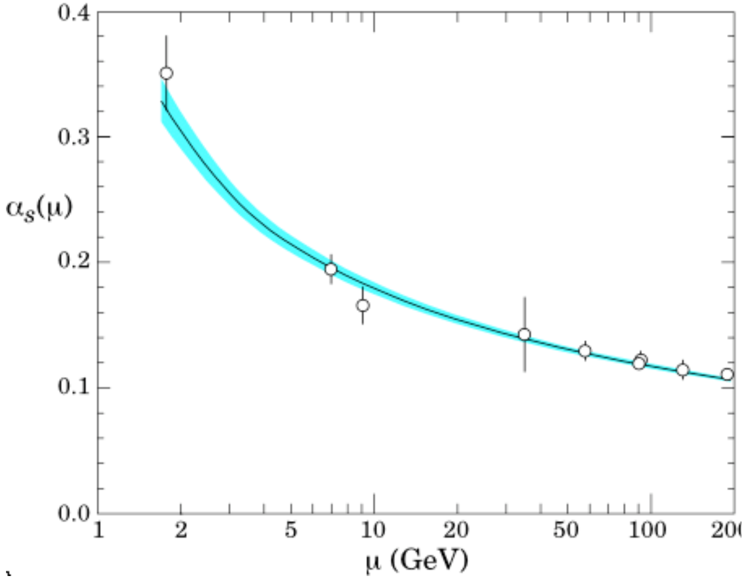
model-dependent

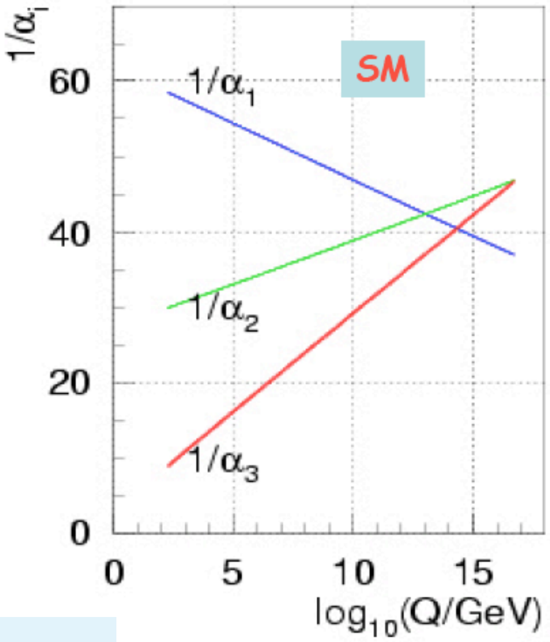
In MSSM the LSP neutralino is heavier than about 50 GeV

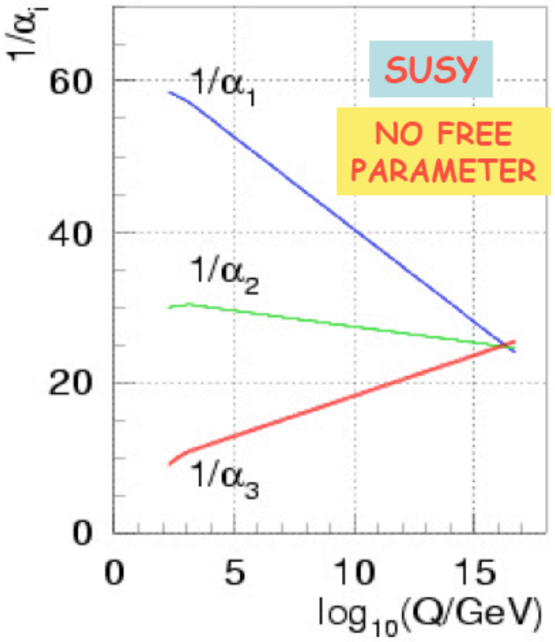
Not much has been done outside the MSSM frame

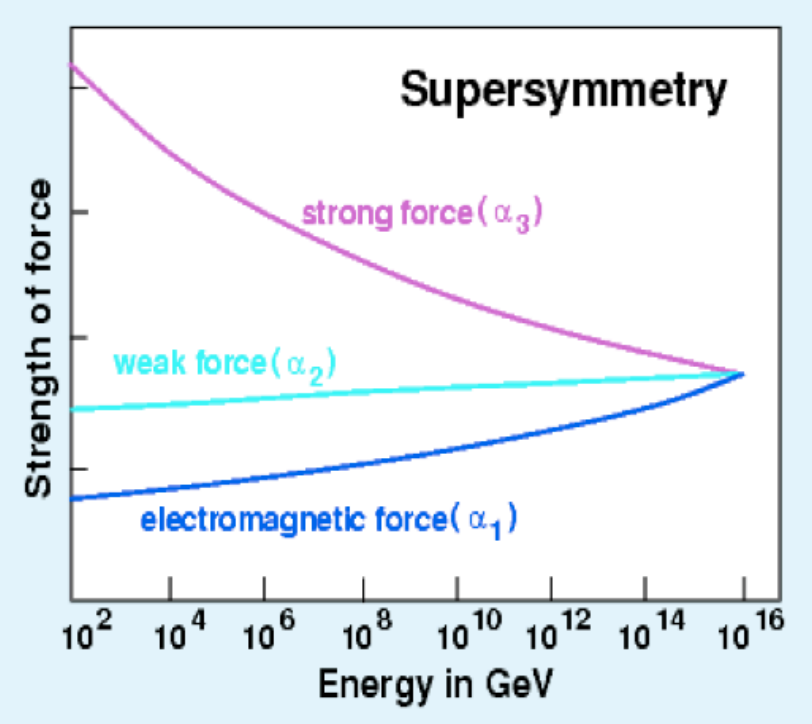
quasi perfect convergence of coupling strengths at 10^{16} GeV in low mass SUSY

2000

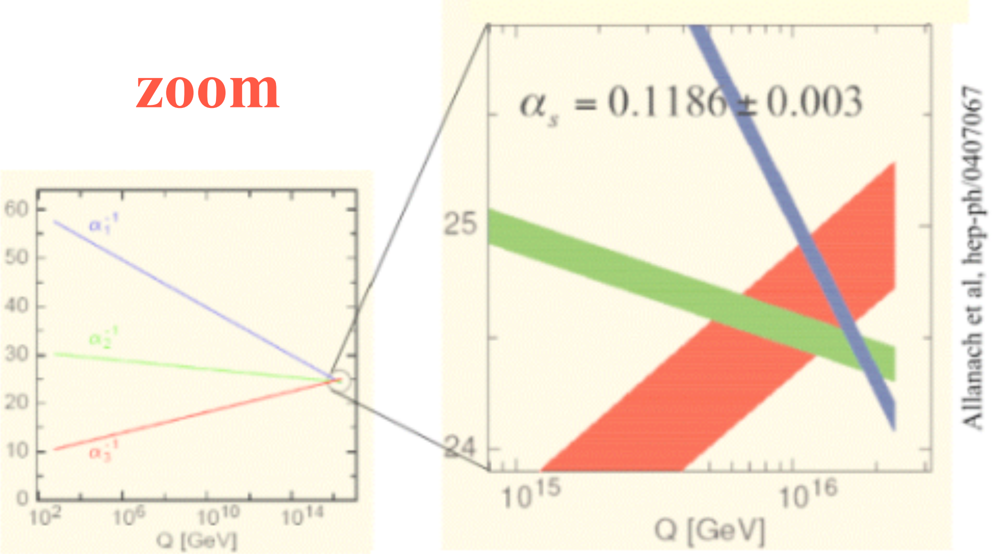






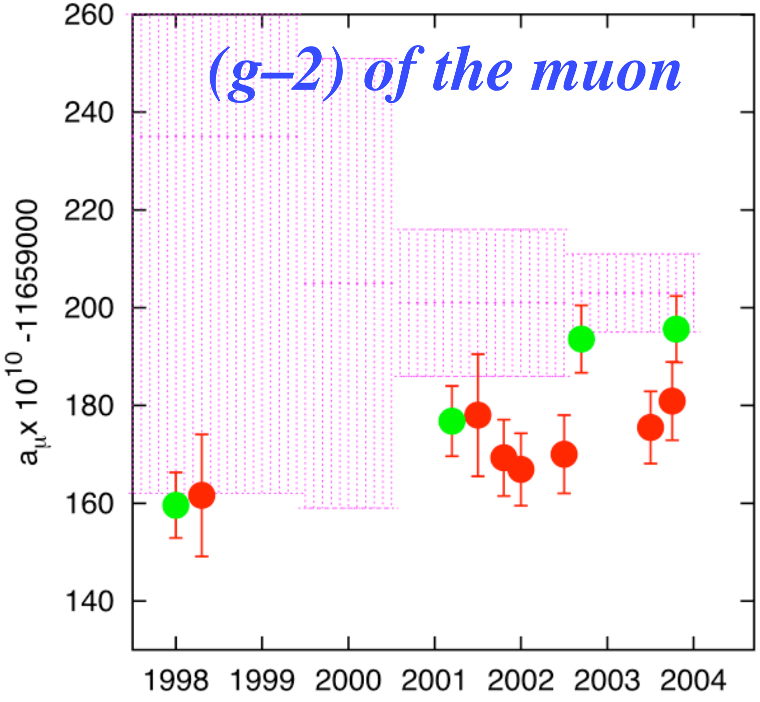


zoom



Allanach et al, hep-ph/0407067

all low energy measurements ~ SM-like, except maybe g-2 of muon



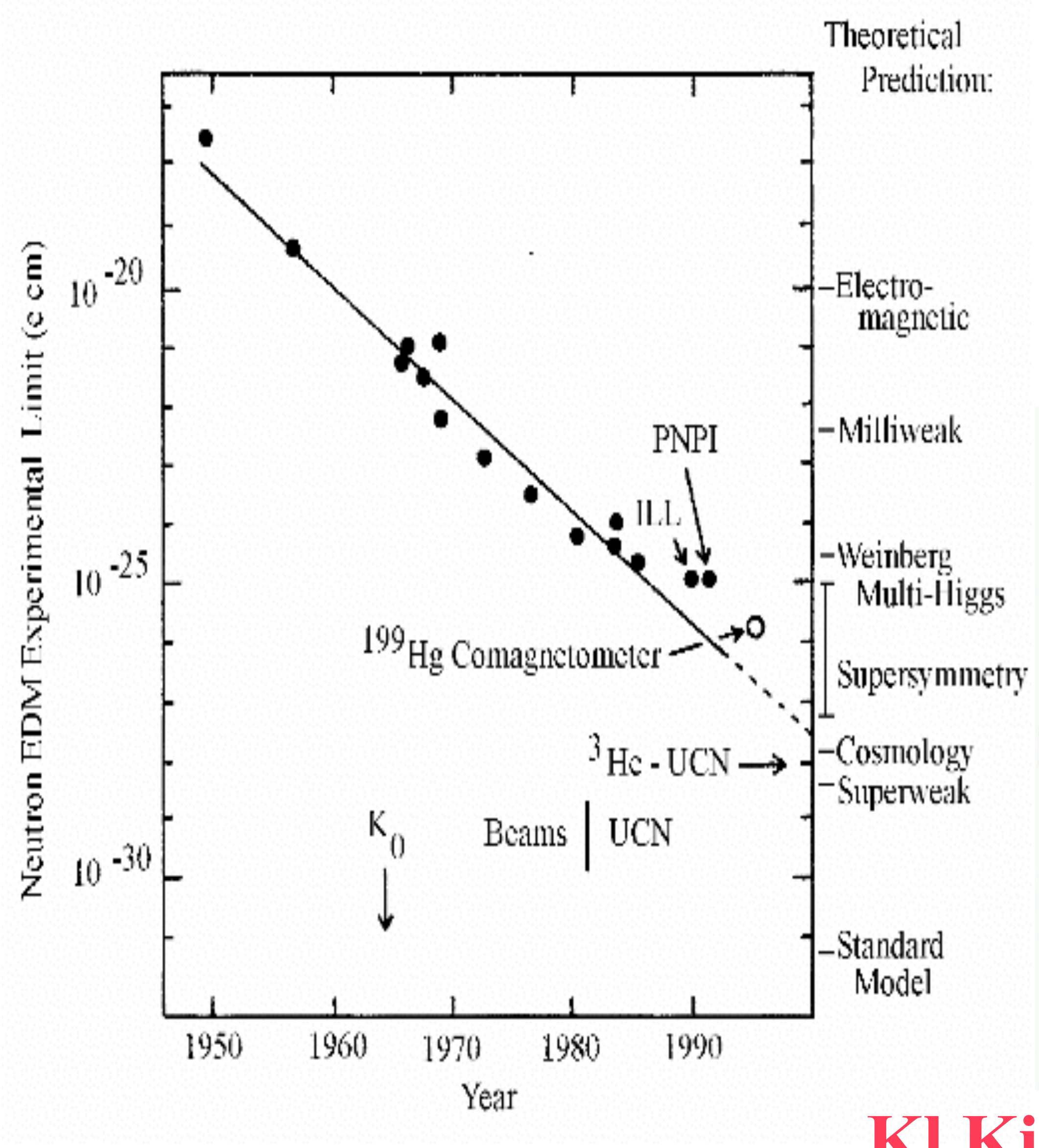
CKM matrix and its unitarity

atomic parity violation

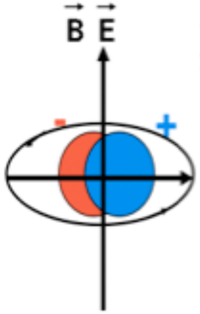
$$Q_W(Cs) = -72.39$$
$$\pm 0.29(exp) \pm 0.51(th)$$
$$(Q_W(Cs)^{SM} = -72.885)$$

hope in B physics,
rare decays,
electric dipole moments
etc

neutron EDM



THE BASIC TECHNIQUE

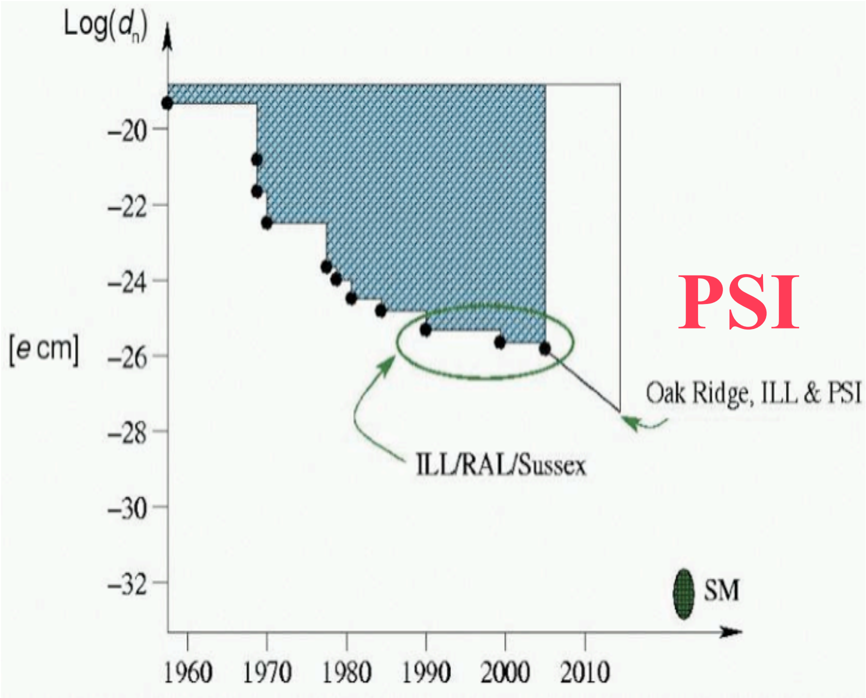


Look for a precession frequency $f_n = \gamma B \pm 2dE$

s = 1/2 dipole moment d_n

10^{-25} e cm in a 10 kV/cm electric field corresponds to a shift in frequency of 0.5 μHz

Motivation: Physics Beyond the Standard Model



PSI

Kl.Kirch

STANDARDISSIMO !

except g–2 of the muon?

But:

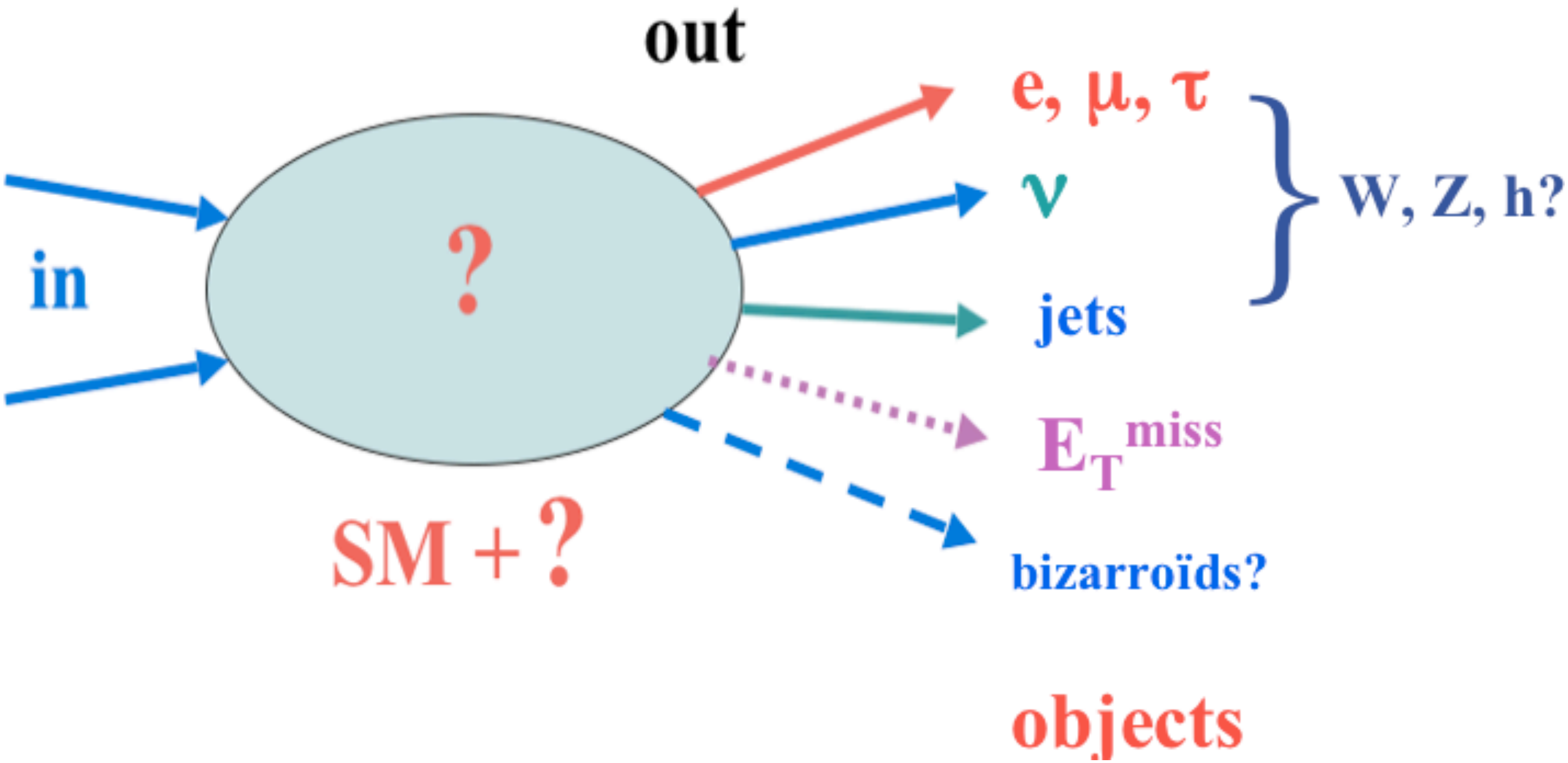
- neutrino masses are not zero
- SM ignores gravity
- dark matter
- convergence of couplings

THE POSSIBLE ROADS

The “agnostic experimentalist”....

Theory inspired scenarios

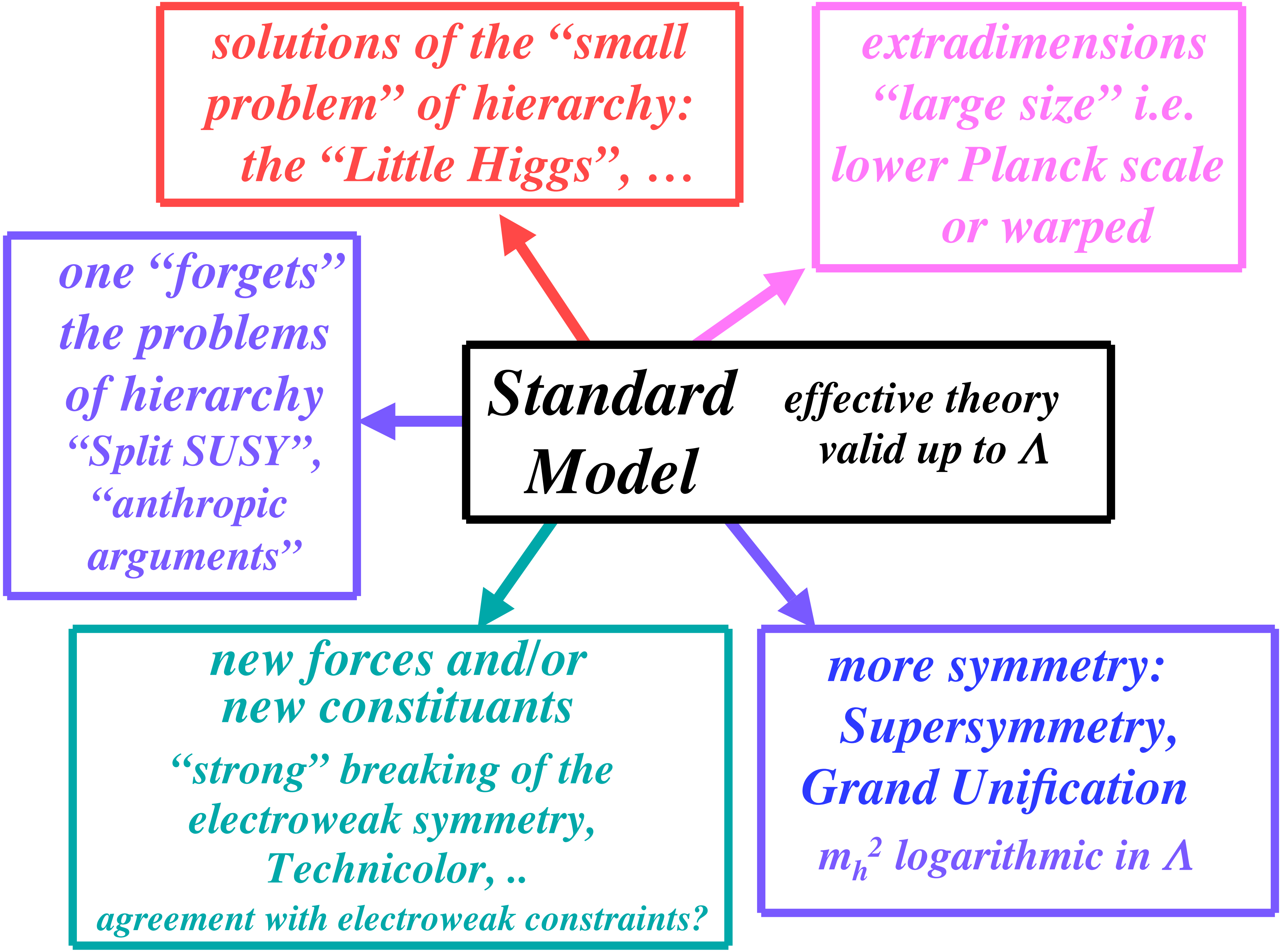
GLIMPSE AT LHC PHYSICS



1/ re-discover the SM

2/ establish the existence of signals BSM, if any

3/ find out what they are: the LHC “inverse problem”



solutions of the "small problem" of hierarchy: the "Little Higgs", …

extradimensions
"large size" i.e.
lower Planck scale
or warped

one "forgets" the problems of hierarchy
"Split SUSY",
"anthropic arguments"

Standard Model

effective theory valid up to Λ

new forces and/or
new constituants

"strong" breaking of the electroweak symmetry,
Technicolor, ..

agreement with electroweak constraints?

more symmetry:
Supersymmetry,
Grand Unification

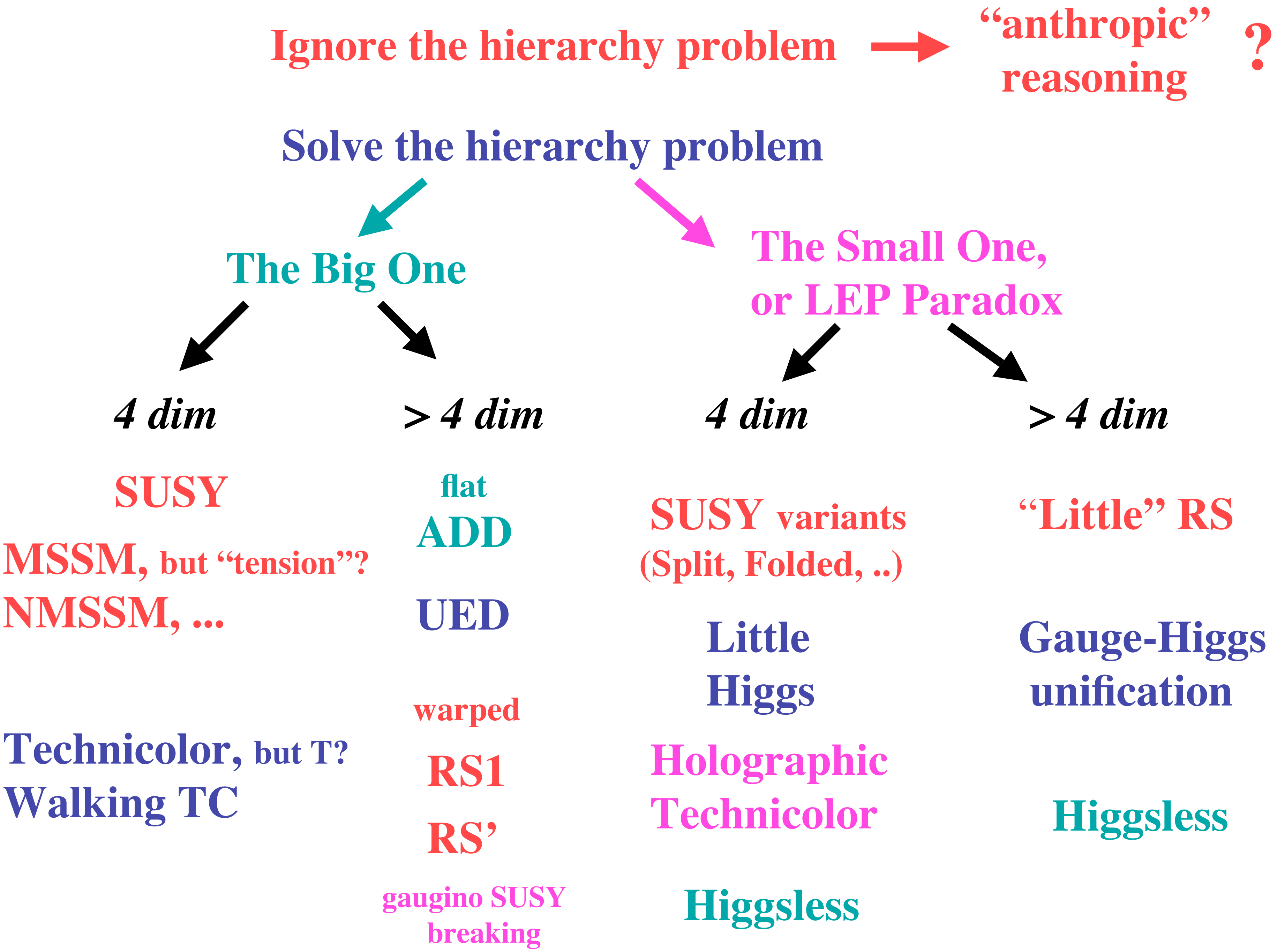
m_h^2 logarithmic in Λ

Remarks

- many BSM models (quickly) reviewed.
  For agnostic experimentalists, the goal is to get as many suggestions of eventual "signatures" as possible: the wilder, the better...

- some "préjugé favorable" concerning SUSY.
  I will be brief on the MSSM and review its variants

- many "theorist" analyses, i.e. at the parton level or so. Excellent. A necessary step to show whether a channel is accessible, but not a sufficient one.



Ignore the hierarchy problem → “anthropic” reasoning ?

Solve the hierarchy problem

- The Big One
  - *4 dim*
    - SUSY
    - MSSM, but “tension”?
    - NMSSM, ...
    - Technicolor, but T?
    - Walking TC
  - *> 4 dim*
    - flat
      - ADD
      - UED
    - warped
      - RS1
      - RS’
      - gaugino SUSY breaking
- The Small One, or LEP Paradox
  - *4 dim*
    - SUSY variants (Split, Folded, ..)
    - Little Higgs
    - Holographic Technicolor
    - Higgsless
  - *> 4 dim*
    - “Little” RS
    - Gauge-Higgs unification
    - Higgsless

SHORT PARENTHESIS

CUSTODIAL SYMMETRY

CUSTODIAL PARITY

- **Higgs potential** $V = \lambda\left(\phi^\dagger\phi - \mu^2\right)^2$ **renormalizable, invariant under SM**

$$\phi = \frac{1}{\sqrt{2}}\begin{pmatrix} \phi_1 + i\phi_2 \\ \phi_4 + i\phi_3 \end{pmatrix} \quad V = \frac{\lambda}{4}\left(\phi_1^2 + \phi_2^2 + \phi_3^2 + \phi_4^2 - 2\mu^2\right)^2$$

$SO(4)$ isomorphic to $SU(2)_L \otimes SU(2)_R$

$$\phi_4 = H + v \quad V = \frac{\lambda}{4}\left(\phi_1^2 + \phi_2^2 + \phi_3^2 + H^2 + 2Hv + v^2 - 2\mu^2\right)^2$$

$SO(3)$ isomorphic to $SU(2)_V$ **(diagonal part)**

- **origin of SU(2)$_R$? see later**

ϕ_i and i ε_{ij} $(\phi^*)^j$ transform the same way

build the matrix

$(\phi \quad \varepsilon\phi^*)$

$$\phi = \frac{1}{\sqrt{2}}\begin{bmatrix} \phi_4 - i\phi_3 & \phi_1 + i\phi_2 \\ -(\phi_1 - i\phi_2) & \phi_4 + i\phi_3 \end{bmatrix} \quad \phi' = U_L \ \phi \ U_R^\dagger$$

$Tr(\phi^\dagger\phi)$ **is left invariant** $\quad U_{L(R)} \in SU(2)_{L(R)}$

$$\theta_L = \theta_R \rightarrow SU(2)_V$$

Parenthesis: Custodial Parities

remember R-parity

$$R_P = (-1)^{\overset{\text{Baryonic Number}}{3B}+\underset{\text{Leptonic number}}{L}+2\overset{\text{Spin}}{S}}$$

→ +1 for Standard Particles

→ -1 for Supersymmetric Partners

● KK-parity

In UED no reference brane is breaking translation invariance in ED. This implies ED momentum conservation. After compactification and inclusion of boundary terms at fixed points, the conservation law preserves a discrete parity called KK-parity.
The KK parity of the nth KK mode is $(-1)^n$.
The first KK can only be pair-produced and their virtual effect comes only from loops.

● T-parity

In Little Higgs models it exchanges the $[SU(2)\times U(1)]_1$ and $[SU(2)\times U(1)]_2$ gauge factors.
SM gauge bosons are T-even, the new heavy ones T-odd. All the SM fermions are T-even.

Results:

★ new particles produced in pairs

★ they intervene in e.w. at loop level, not tree level

★ bonus of a potential candidate for dark matter, the lightest odd-parity particle

- **custodial symmetry** plus **custodial parity**

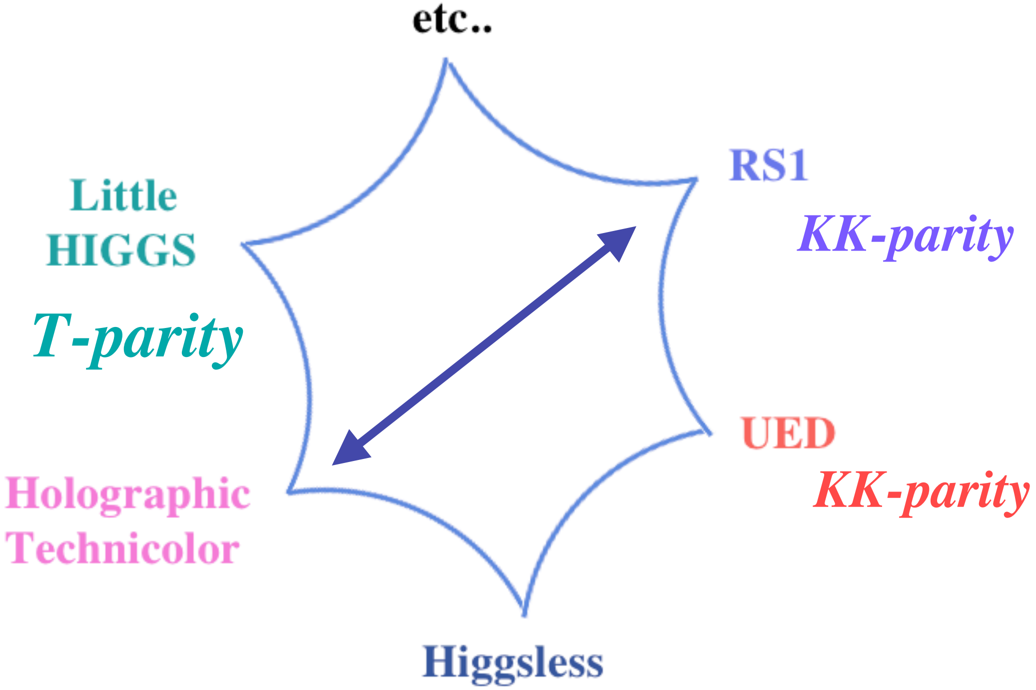
to satisfy e.w. constraints

to allow for lighter objects, for a DM candidate, to satisfy e.g. R_b etc..

then all models look somewhat alike, and like SUSY with R-parity

they differ however in spin, in the number of recurrences

LHC “inverse problem”


etc..

RS1

KK-parity

Little HIGGS

T-parity

UED

KK-parity

Holographic Technicolor

Higgsless

- The AdS/CFT correspondance links 5D (RS) and 4D (Technicolor)

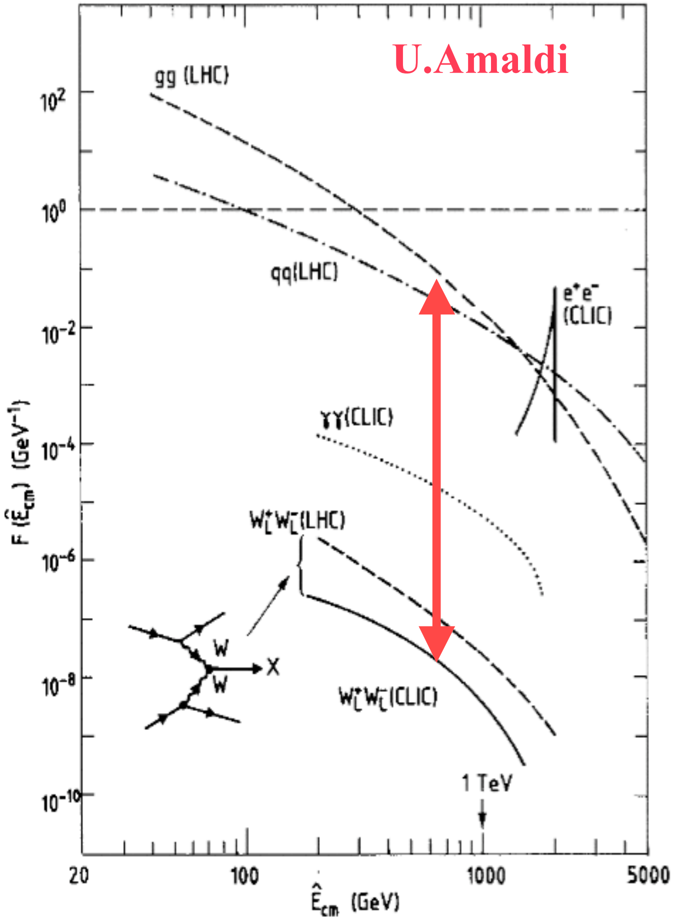
5th dimension ⟷ energy scale

deconstruction,
5th dimension on a lattice, etc

Is the 5th dim real or metaphoric? cf Correspondance Principle?

Experimentalist questions concerning BSM physics

- are the new objects sufficiently coupled to LHC colliding partons?
e.g. yes if they carry SM color and are produced by QCD
Or should one rely on vector boson fusion?


U.Amaldi

- which type of signals can one expect?

	no light vector resonance	light vector resonances
no light Higgs	Chiral lagrangians	LSTC Higgsless (D)BESS
light Higgs	SM, Strongly Interacting Light Higgs (SILH)	Warped/composite- Holographic-, Little- Gaugephobic-, Twin-Higgs LDBESS, Gauge-Higgs

from C.Grojean

- what are the main decay modes to expect? e.g. more difficult situation if the decays are mostly into top pairs

(SUSY) HIGGSLESS COMPOSITE

VV amplitude without any KK → $A(VV)$

mass of first KK vector → $m_{\hat{V}}$

coupling to light fermions → $f\bar{f}\hat{V}$

coupling to 3rd generation → $Q_3\bar{Q}_3\hat{V}$

	Higgsless	Composite
$A(VV)$	$\approx s/v^2$	$\approx s/f^2$
$m_{\hat{V}}$	$\approx g_S v$	$\approx g_S f$
$\hat{V}VV$	g_S	g_S
$f\bar{f}\hat{V}$	$\approx g(g/g_S)$	$\approx g(g/g_S)$
$Q_3\bar{Q}_3\hat{V}$	?	strongish
KK – quarks	–	Yes, with $\approx$ TeV mass

v =175 GeV

$\int L\,dt \leq 1\,fb^{-1}$	mSUGRA
	$pp \rightarrow \tilde{g}\tilde{g}, \tilde{t}\tilde{t}$
	$\chi \rightarrow g_{3/2} + \gamma/Z/h$
	R-hadrons
$\int L\,dt = 1 \div 30\,fb^{-1}$	SM-like Higgs boson
	KK quarks
$\int L\,dt > 30\,fb^{-1}$	Susy Higgs boson system
	Minimal Dark Matter
	KK weak bosons
	KK gluons

Barbieri 0802.3988

Rather than on physics scenarios (of which at most one is correct) one should focus on all accessible topologies (i.e. instrumentally manageable and for which the SM “background” is mastered)

n leptons + m photons + p jets (+ E_T^{miss})

Re-discover the SM

first benchmarks are ratios (W/Z, jets “in”/jets “out”, etc

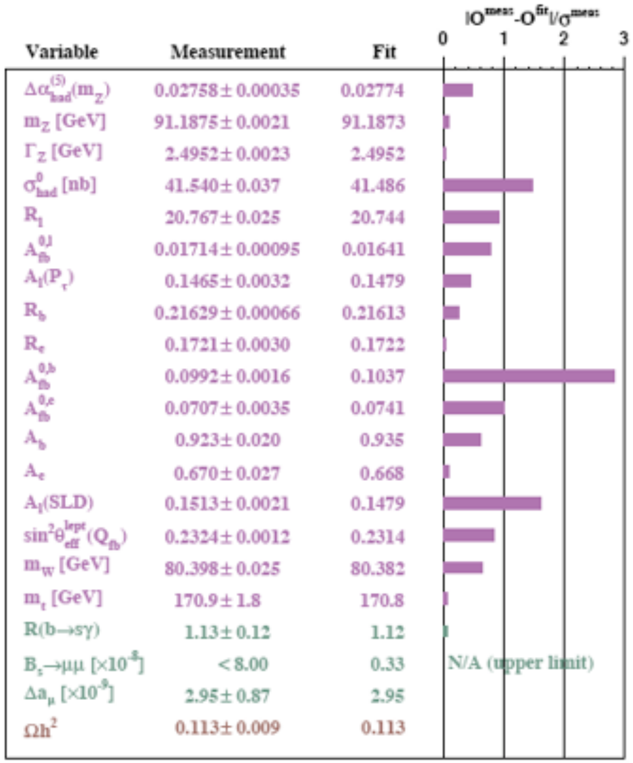
check e/μ universality

Promising search channels are:

di-leptons (“Drell-Yan”)
di-jets
di-bosons, e.g. WZ
top-antitop

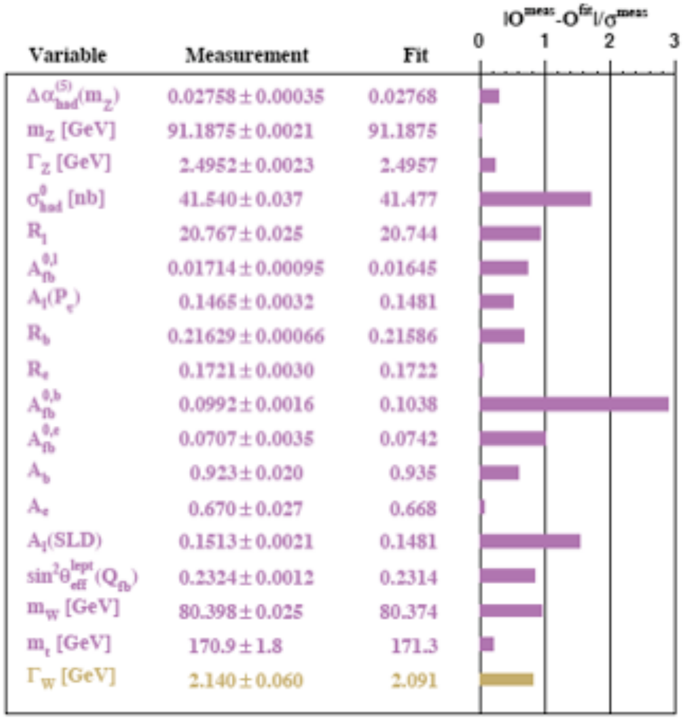
and peculiar signatures: heavy stables, displaced vertices

Back up



Variable	Measurement	Fit	$\|O^{meas}-O^{fit}\|/\sigma^{meas}$
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02774	
m_Z [GeV]	91.1875 ± 0.0021	91.1873	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952	
σ_{had}^0 [nb]	41.540 ± 0.037	41.486	
R_l	20.767 ± 0.025	20.744	
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01641	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479	
R_b	0.21629 ± 0.00066	0.21613	
R_c	0.1721 ± 0.0030	0.1722	
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1037	
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0741	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1479	
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.382	
m_t [GeV]	170.9 ± 1.8	170.8	
$R(b\to s\gamma)$	1.13 ± 0.12	1.12	
$B_s\to\mu\mu$ [$\times10^{-8}$]	< 8.00	0.33	N/A (upper limit)
Δa_μ [$\times10^{-9}$]	2.95 ± 0.87	2.95	
Ωh^2	0.113 ± 0.009	0.113	

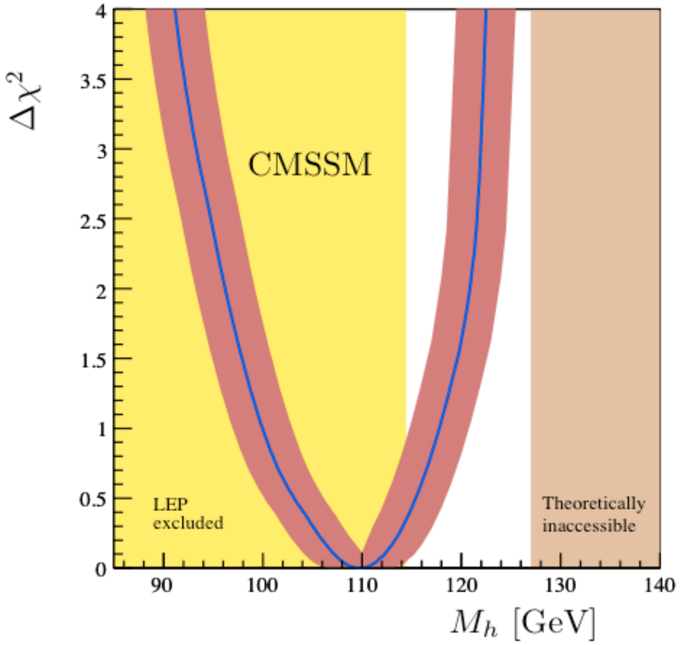
CMSSM
24-20%
incl/excl. m_h



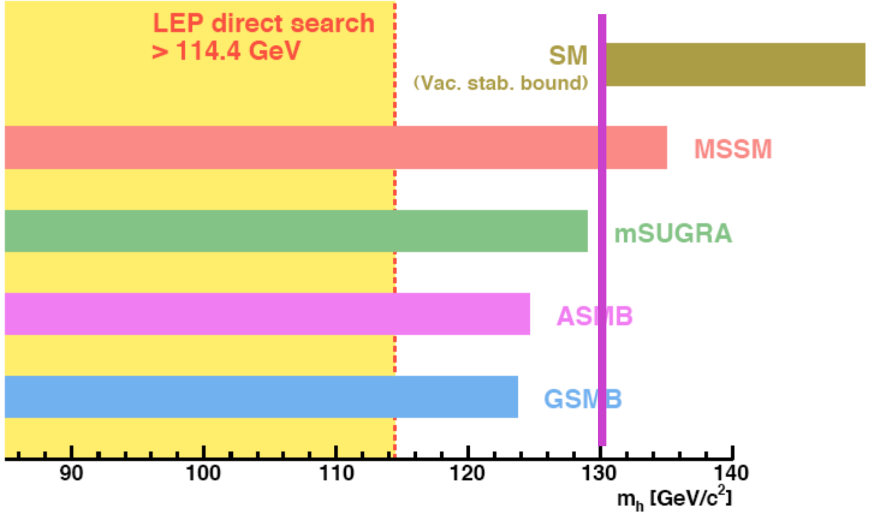
Variable	Measurement	Fit	$\|O^{meas}-O^{fit}\|/\sigma^{meas}$
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02768	
m_Z [GeV]	91.1875 ± 0.0021	91.1875	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957	
σ_{had}^0 [nb]	41.540 ± 0.037	41.477	
R_l	20.767 ± 0.025	20.744	
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01645	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481	
R_b	0.21629 ± 0.00066	0.21586	
R_c	0.1721 ± 0.0030	0.1722	
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1038	
$A_{fb}^{0,c}$	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	
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.374	
m_t [GeV]	170.9 ± 1.8	171.3	
Γ_W [GeV]	2.140 ± 0.060	2.091	

SM
15-15%

Heinemeyer,
Daegu 2007



SUSY well hidden,
but h0 nearby!



$$(1-\frac{m_W^2}{m_Z^2})\frac{m_W^2}{m_Z^2} = \frac{\pi\alpha(m_Z)}{\sqrt{2}G_F m_Z^2(1-\Delta r_W)}$$

$$g_A = -\frac{\sqrt{\rho}}{2} \sim -\frac{1}{2}(1+\frac{\Delta\rho}{2}),$$

$$x = \frac{g_V}{g_A} = 1-4\sin^2\theta_{eff} = 1-4(1+\Delta k)s_0^2.$$

$$\begin{aligned}
\epsilon_1 &= \Delta\rho, \\
\epsilon_2 &= c_0^2\Delta\rho + \frac{s_0^2\Delta r_W}{c_0^2-s_0^2} - 2s_0^2\Delta k, \\
\epsilon_3 &= c_0^2\Delta\rho + (c_0^2-s_0^2)\Delta k.
\end{aligned}$$

$$\begin{aligned}
\frac{m_W^2}{m_Z^2} &= \frac{m_W^2}{m_Z^2}|_B(1+1.43\epsilon_1-1.00\epsilon_2-0.86\epsilon_3) \\
\Gamma_l &= \Gamma_l|_B(1+1.20\epsilon_1-0.26\epsilon_3), \\
A_l^{FB} &= A_l^{FB}|_B(1+34.72\epsilon_1-45.15\epsilon_3), \\
\Gamma_b &= \Gamma_b|_B(1+1.42\epsilon_1-0.54\epsilon_3+2.29\epsilon_b).
\end{aligned}$$

$$\begin{aligned}
\epsilon_1 &= \frac{3G_F m_t^2}{8\pi^2\sqrt{2}} - \frac{3G_F m_W^2}{4\pi^2\sqrt{2}}\tan^2\theta_W \ln\frac{m_H}{m_Z} + \ldots, \\
\epsilon_2 &= -\frac{G_F m_W^2}{2\pi^2\sqrt{2}}\ln\frac{m_t}{m_Z} + \ldots., \\
\epsilon_3 &= \frac{G_F m_W^2}{12\pi^2\sqrt{2}}\ln\frac{m_H}{m_Z} - \frac{G_F m_W^2}{6\pi^2\sqrt{2}}\ln\frac{m_t}{m_Z}\ldots., \\
\epsilon_b &= -\frac{G_F m_t^2}{4\pi^2\sqrt{2}} + \ldots.
\end{aligned}$$

custodial symmetry

SUSY

→ great merits from the theoretical side

→ relatively abundantly produced

→ mostly MSSM and SUGRA are studied

- $m_h > 114$ GeV → some "tension", O(1%) fine tuning

  ways to escape:

  ? we missed a non SM-like light Higgs at LEP: e.g. h (97) → aa → 4 τ (0801.4554)

  ? consider hidden sectors: "Hidden Valleys", etc (0712.2041)

  ? move to NMSSM: proposed benchmarks (0801.4321)

  ? ignore the tension: Split SUSY → long-lived gluino, R-hadrons

  (0612161, 0611040)

- R-parity? proton stability, LSP dark matter, missing E_T

  but is it wishful thinking?

  proposed benchmarks (0710.2287)

- missing E_T + ... as a privileged handle

  but try also "positive" identification (0801.3799)