

What would it mean

if

the LHC finds

no evidence

for the

Higgs Boson ?

No Higgs
at the LHC ?



No Higgs
at the LHC !

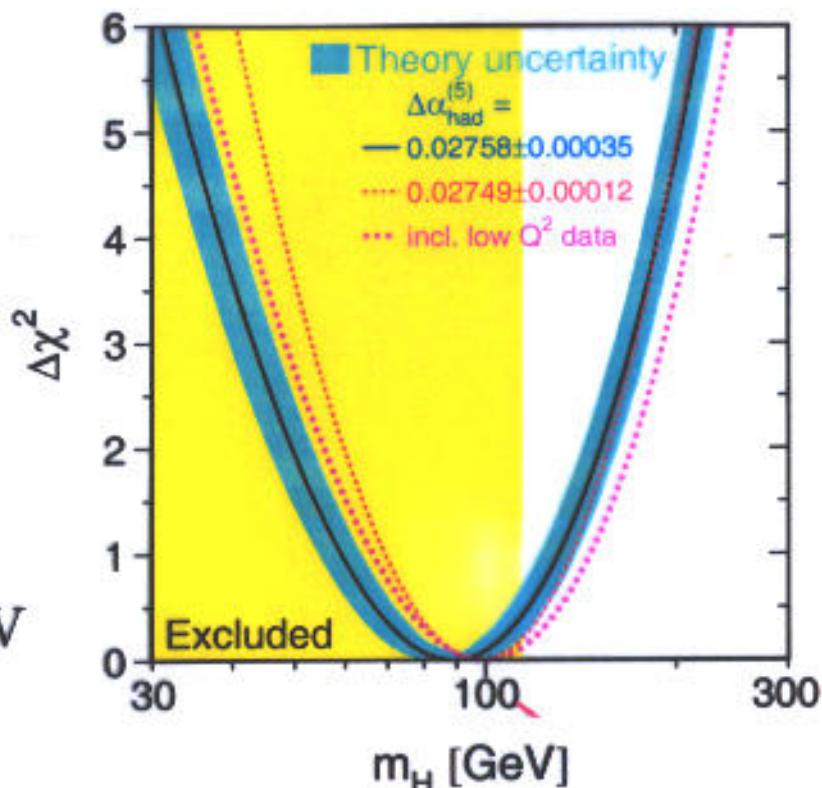
The EWWG Analysis

The pseudo-observables depend on the mass of the (unobserved) Higgs boson: M_H .

EWWG combines measurements coming from LEP, SLD, CDF, and D0 with SM theoretical predictions in a $\Delta\chi^2$ curve: the Blue Band

$$M_H = 89^{+42}_{-30} \text{ GeV} \quad M_H^{95} = 175 \text{ GeV}$$

(Winter 06)



Fits to the M_H mass

- leptonic observables

$$(\sin^2 \theta_{eff})_l = 0.23113 \pm 0.00020$$

$$M_H = 51^{+37}_{-22} \text{ GeV} \quad M_H^{95} = 124 \text{ GeV}$$

- combined fit

$$(\sin^2 \theta_{eff})_l \text{ and } M_W = 80.404 \pm 0.030 \text{ GeV}$$

$$M_H = 51^{+30}_{-21} \text{ GeV} \quad M_H^{95} = 109 \text{ GeV}$$

- hadronic observables

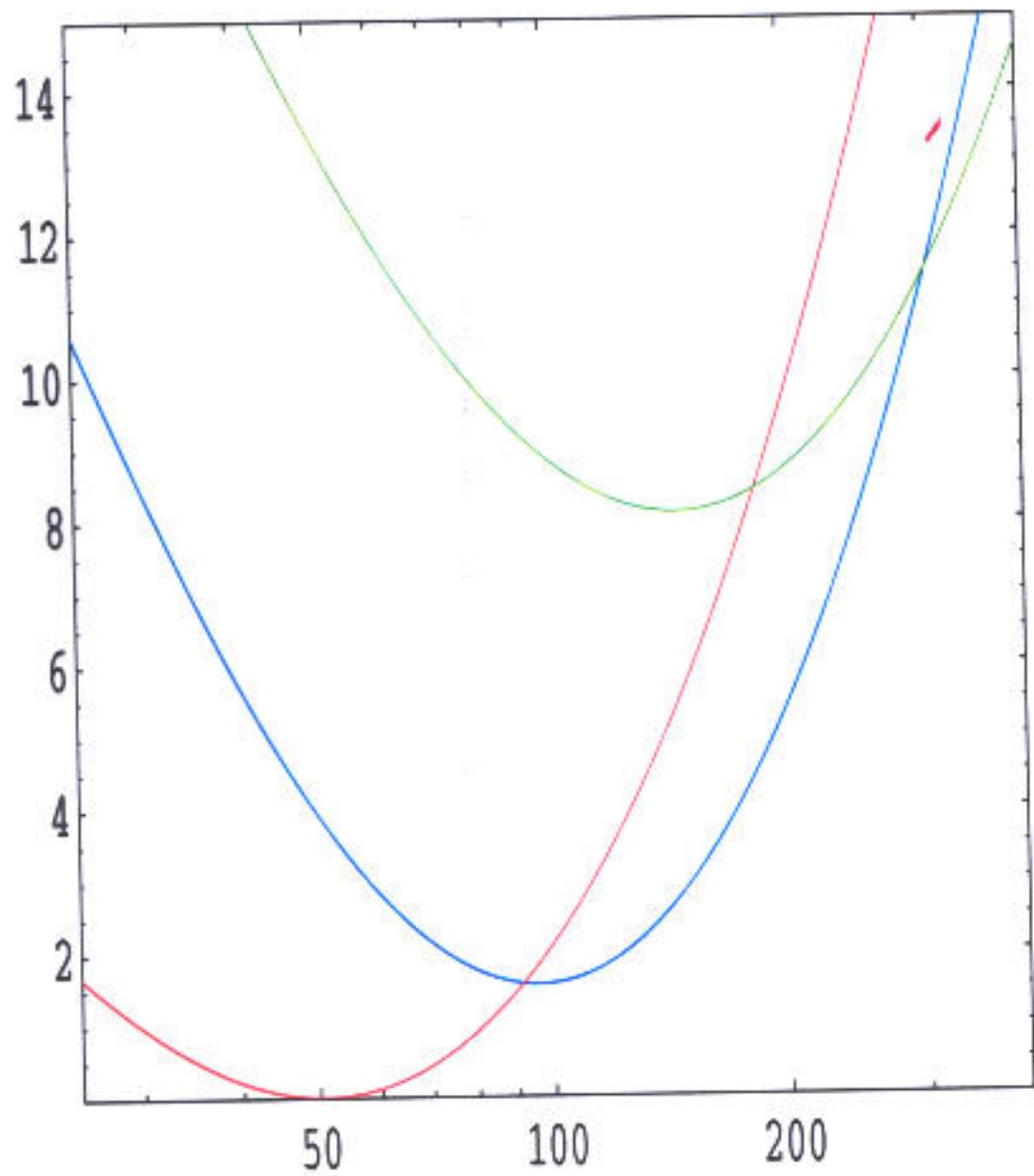
$$(\sin^2 \theta_{eff})_{\text{bottom}} = 0.23222 \pm 0.00027$$

$$M_H = 488^{+426}_{-219} \text{ GeV} \quad (M_H^{95})_{\text{l.b.}} = 181 \text{ GeV}$$

$$m_t = 172.5 \pm 2.3 \text{ GeV} \quad \Delta \alpha_h^{(5)} = 0.02758 \pm 0.00035$$

$$\alpha_s(M_Z) = 0.118 \pm 0.002$$

χ^2 for $\sin^2 \theta_{eff}^{lept}$ and M_W as a function of M_H



The red line corresponds to $\sin^2 \theta_{eff}^{lept}$ from leptonic data, the blue one to the world average for $\sin^2 \theta_{eff}^{lept}$, and the green one to $\sin^2 \theta_{eff}^{lept}$ from the hadronic data

Could the Higgs be too heavy?
($\gtrsim 1 \text{ TeV}$)

$$m_H^2 = \lambda v^2 \quad \text{heavy Higgs - strong interaction}$$

Difficult question higher loops important
addressed by: (Moriond 1984)

van der Bij, Veltman, Kryiaziou,
Jikia, Borodulin, Ghinculea (2-loop)

Binoth, Akhoury, Wang (γ_N expansion)

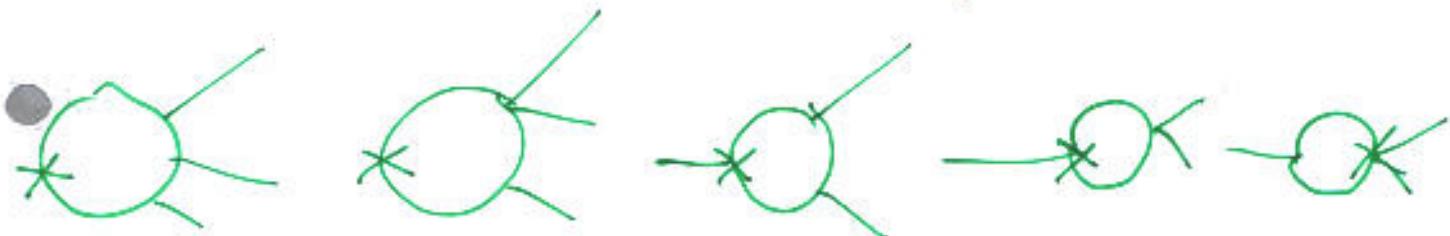
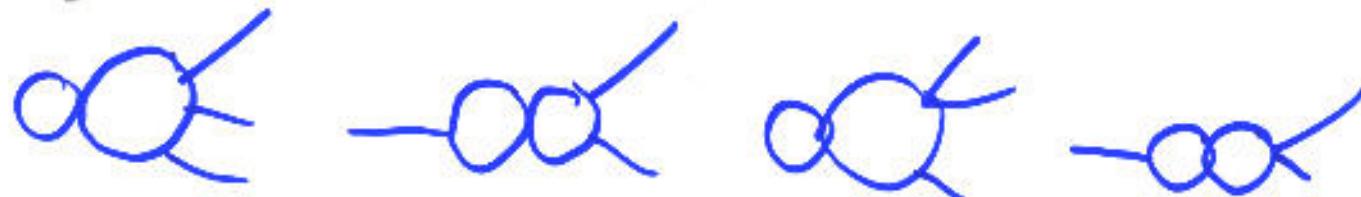
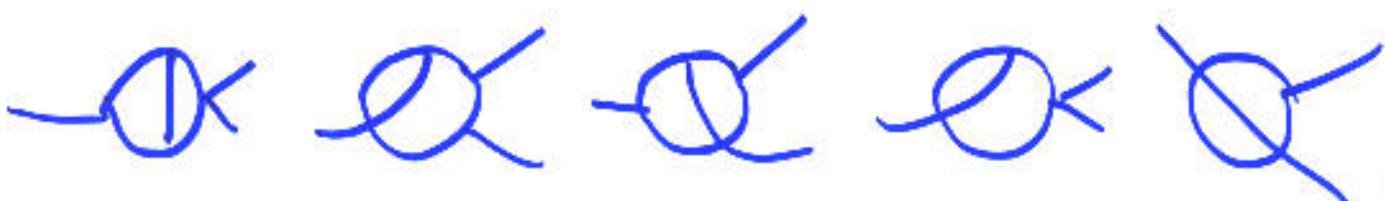
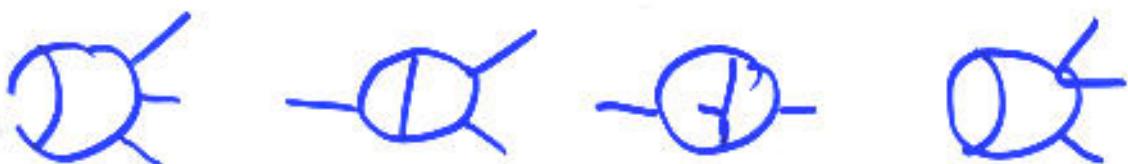
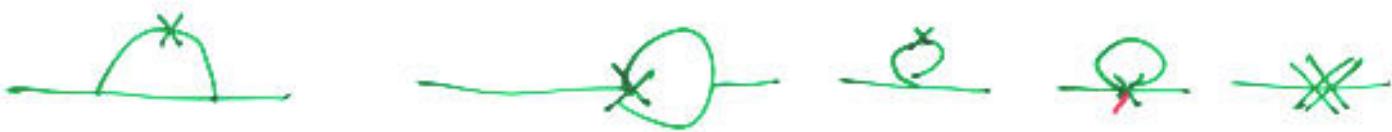
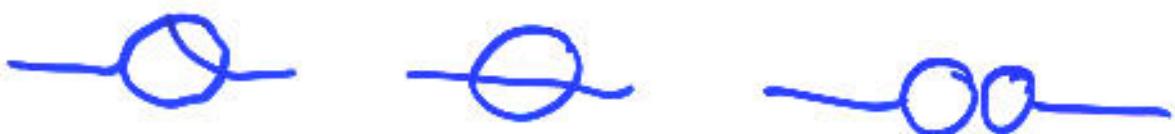
Dilcher (non-perturbative)

Kastening (non-linear model)

Boughzeal, Tausk (3-loop)

($\approx 500,000$ Feynman graphs)

Answer: no the Higgs cannot be too heavy



Reduction of graphs with
schoonschip and/or form

$$(2M/M_1/\Omega_2) = \pi^4 \left[\frac{-2}{\epsilon^2} + \frac{1}{\epsilon} \left(1 - 2 \log M^2 \right) - \frac{1}{2} - \frac{\pi^2}{12} \right. \\ \left. + \log M^2 - \log^2 M^2 - f(a, b) \right]$$

$$a = \frac{M_1^2}{n^2} \quad b = \frac{M_2^2}{M^2}$$

$$f(a, b) = -\frac{1}{2} \log a \log b +$$

$$\left(\frac{a+b-1}{\sqrt{n}} \right) \left[Sp\left(-\frac{x_2}{y_1} \right) + Sp\left(-\frac{y_2}{x_1} \right) + \frac{1}{4} \log^2 \frac{x_2}{y_1} \right.$$

$$\left. + \frac{1}{4} \log^2 \frac{y_2}{x_1} + \frac{1}{4} \log^2 \frac{x_1}{y_1} - \frac{1}{4} \log^2 \frac{x_2}{y_2} + \frac{\pi^2}{6} \right]$$

$$x_1 = \frac{1}{2} (1 + b - a + \sqrt{n}) \quad x_2 = \frac{1}{2} (1 + b - a - \sqrt{n})$$

$$y_1 = \frac{1}{2} (1 + a - b + \sqrt{n}) \quad y_2 = \frac{1}{2} (1 + a - b - \sqrt{n})$$

$$\sqrt{n} = (1 - 2(a+b) + (a-b)^2)^{1/2}$$

$$\text{Special case } f(1,1) = \frac{2}{\sqrt{3}} \operatorname{Cl}\left(\frac{\pi}{3}\right)$$

$$\operatorname{Cl}(x) = \sum_{n=1}^{\infty} \frac{\sin nx}{n^2} \quad \frac{2}{\sqrt{3}} \operatorname{Cl}\left(\frac{\pi}{3}\right) = 1.171953619 \dots$$

$$\delta g = -\frac{3g^2}{64\pi^2} + g^4 \log \frac{m_H^2}{m_W^2} + \frac{g^4}{2048\pi^4} \frac{m_H^2}{m_W^2} \text{tg}^6 \theta \left\{ -\frac{21}{8} + \frac{3\pi^2}{4} + \frac{9\pi\sqrt{3}}{4} - 27\mathcal{O}\ell \right\}$$

$$= -2.87 \cdot 10^{-3} - 5.7 \cdot 10^{-4} \log m^2 + 4.6 \cdot 10^{-5} m^2 \quad m_H \text{ (TeV)}$$

$$\frac{\delta M_W}{M_W} = 5.3 \cdot 10^{-4} + 1.0 \cdot 10^{-4} \log m^2 + 4.6 \cdot 10^{-5} m^2$$

$$\frac{\delta M_Z}{M_Z} = 1.3 \frac{\delta M_W}{M_W} - 1.5 \cdot 10^{-5} m^2$$

$$\frac{k_f}{e} = 4.2 \cdot 10^{-4} - 3.6 \cdot 10^{-5} m^2 \quad k_W = -0.55 k_f$$

$$\delta R_g = -5.3 \cdot 10^{-4} - 1.0 \cdot 10^{-4} \log m^2 - 3.8 \cdot 10^{-5} m^2$$

Very small coefficient for the m^2 -term ; cancellation between coefficients

● 2-loop 2H exchange

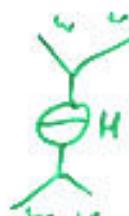
(Spira, Borodau(r))

$$\text{example } 4-Z \text{ vertex : } g_{4Z} \cdot \left(\delta_{\mu_1\mu_2} \delta_{\nu_1\nu_2} + \delta_{\mu_1\mu_3} \delta_{\nu_1\nu_4} + \delta_{\mu_1\mu_4} \delta_{\nu_1\nu_3} \right)$$

$$g_{4Z} = \frac{g^6}{256\pi^4} \frac{m_H^2}{m_W^2} \left\{ \frac{337}{64} - \frac{3g}{16} \pi \cdot \mathcal{O}\ell + \frac{105}{64} \pi \sqrt{3} - \frac{557}{576} \pi^2 - 2\mathcal{O}\ell \sqrt{3} + \frac{63}{16} \mathcal{G}\ell \right\}$$

$$= -1.4g \cdot 10^{-3} m_H^2$$

is enhanced (no cancellation between terms)



Two-loop heavy Higgs propagator

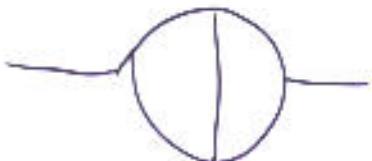
with

A. Ghanevici

1-loop corrections were known to be small

Special 2-loop effect s-dependent width.

new integrals



for arbitrary masses and external momenta

- must be done numerically

Parity reduced to



made as a special fast function

optimized path in complex Feynman parameter

space multi-dimensional deterministic methods

m_H [GeV]	peak shift [GeV]	peak shift [%]	height increase [%]
400	-.072	-.018	.0020
500	-.35	-.070	.012
600	-1.3	-.21	.051
700	-3.8	-.54	.18
800	-9.9	-1.2	.51
900	-23	-2.6	1.3
1000	-49	-4.9	3.0
1100	-97	-8.8	6.5
1200	-178	-15	13
1300	-305	-23	25
1400	-487	-35	45
1500	-721	-48	78
1600	-997	-62	130

Table 1: Leading corrections to the shape of the Higgs resonance $|\frac{1}{p^2 - m_H^2 - iIm\Sigma}|^2$. The Breit-Wigner resonance with constant width calculated at order $(g^2 \frac{m_H^2}{m_W^2})^2$ is compared to the resonance corrected for the energy dependence of the two-loop selfenergy.

with A. Glinevich
and T. Bischoff

Large effect at two-loop

Non-perturbative?

rewrite linear sigma-model

$$L = -\frac{1}{2} \partial_\mu \bar{\pi}_i \partial_\mu \bar{\pi}_i - \frac{\lambda}{\sqrt{N}} (\bar{\pi}_i \bar{\pi}_i - f^4)^2$$

$$\begin{aligned} i &= 1 \dots N \\ (\text{nature } N &= 4) \end{aligned}$$

Resumming Goldstone-loops

---000---000---

tachyon subtraction and non-perturbative regularization

$$\begin{aligned}
i\alpha(s) &= A_1 + A_2 + A_3 + \text{counterterms} \\
&\quad + A_4 + A_5 + \text{counterterms} \\
i\frac{v^2}{N}\beta(s) &= B_1 + B_2 + \text{counterterms} \\
i\frac{v}{\sqrt{N}}\gamma(s) &= C_1 + C_2 + \text{counterterms} \\
i\frac{v^2}{N}\delta(s) &= D + \text{counterterms}
\end{aligned}$$

= $\chi\chi$
 = $\sigma\chi$
 = $\sigma\sigma$
 = $\pi\pi$

Figure 2: Infinite sums of multiloop Feynman diagrams which contribute in next-to-leading order in $1/N$ to the two-point functions of the $O(N)$ sigma model. The blob on propagators denotes the summed-up leading order propagators. Note that the $\pi\pi$ propagator at leading order in $1/N$ is a free propagator. One of the graphs above is shown in expanded form in fig. 3.

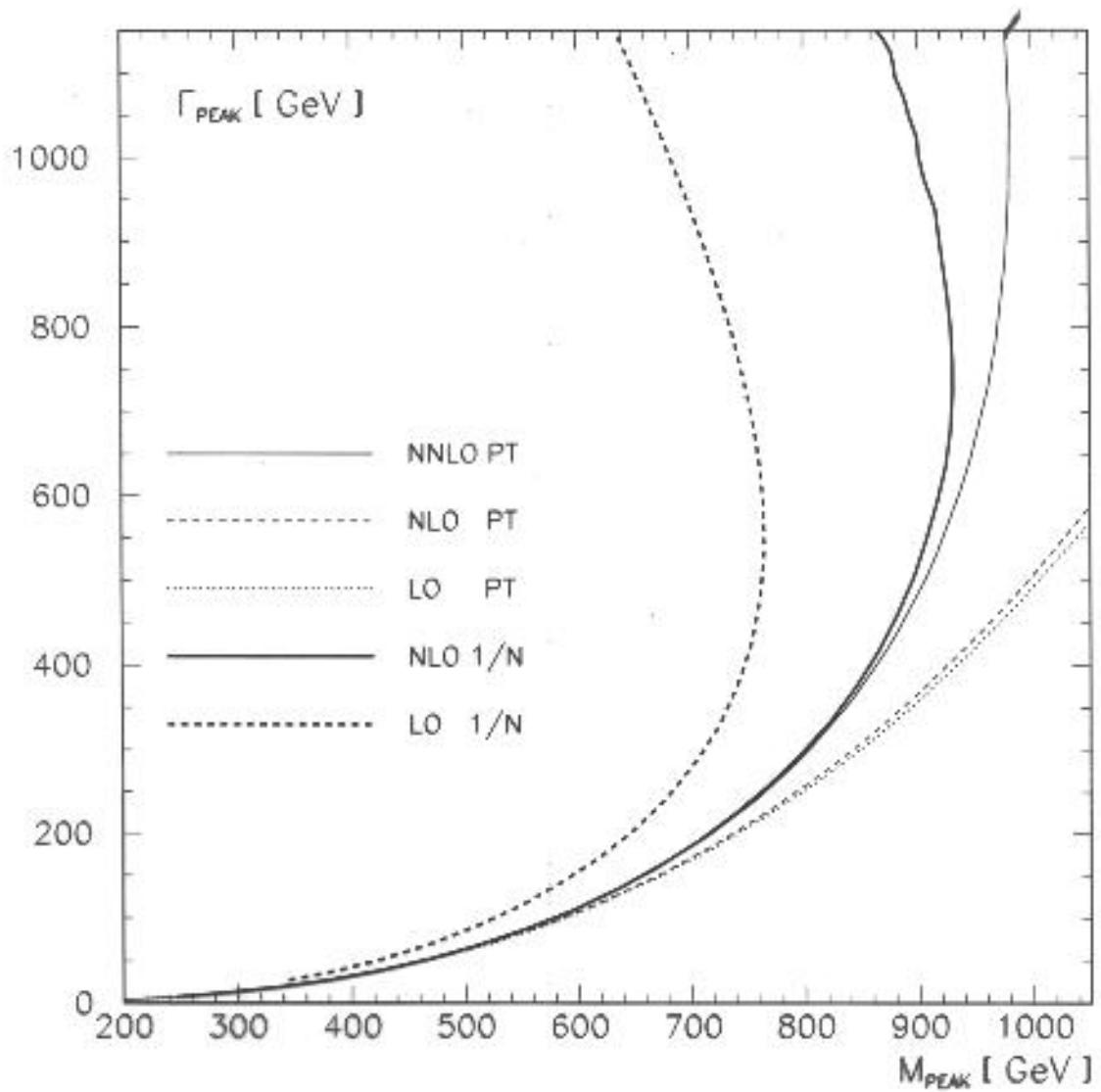


Figure 1: Width versus mass of the Higgs-boson in perturbation theory and in the $1/N$ expansion.

with B. Taush e
R. Boughezal

with

$$\Delta\rho^{(1)} = -\frac{3}{4} \frac{g^2}{16\pi^2} \frac{s_W^2}{c_W^2} \log\left(\frac{m_H^2}{M_W^2}\right), \quad (41)$$

$$\begin{aligned} \Delta\rho^{(2)} &= \left(\frac{g^2}{16\pi^2}\right)^2 \frac{s_W^2}{c_W^2} \frac{m_H^2}{M_W^2} \left(-\frac{21}{64} + \frac{9}{32}\pi\sqrt{3} + \frac{3}{32}\pi^2 - \frac{9}{8}C\sqrt{3}\right) \\ &= \left(\frac{g^2}{16\pi^2}\right)^2 \frac{s_W^2}{c_W^2} \frac{m_H^2}{M_W^2} (0.1499), \end{aligned} \quad (42)$$

$$\begin{aligned} \Delta\rho^{(3)} &= \left(\frac{g^2}{16\pi^2}\right)^3 \frac{s_W^2}{c_W^2} \frac{m_H^4}{M_W^4} \left(-\frac{21}{512} + \frac{729}{512}\pi\sqrt{3} - \frac{3391}{4608}\pi^2 - \frac{9}{16}\pi C \right. \\ &\quad \left. - \frac{1577}{2304}\pi^3\sqrt{3} - \frac{9109}{69120}\pi^4 + \frac{99}{16}\sqrt{3}\log 3 C \right. \\ &\quad \left. - \frac{297}{32}\sqrt{3}\text{Ls}_3(2\pi/3) - \frac{399}{16}\sqrt{3}C + \frac{3043}{128}\zeta(3) \right. \\ &\quad \left. + \frac{567}{32}C^2 + \frac{109}{8}U_{3,1} - 36V_{3,1} \right) \\ &= \left(\frac{g^2}{16\pi^2}\right)^3 \frac{s_W^2}{c_W^2} \frac{m_H^4}{M_W^4} (-1.7282). \end{aligned} \quad (43)$$

The constants appearing in $\Delta\rho^{(3)}$ are defined by [24, 25]

$$\begin{aligned} U_{3,1} &= \frac{1}{2}\zeta(4) + \frac{1}{2}\zeta(2)\log^2 2 - \frac{1}{12}\log^4 2 - \text{Li}_4\left(\frac{1}{2}\right) \\ &= -0.11787599965 \end{aligned} \quad (44)$$

$$\begin{aligned} V_{3,1} &= \sum_{m>n>0} \frac{(-1)^m \cos(2\pi n/3)}{m^3 n} \\ &= -0.03901272636 \end{aligned} \quad (45)$$

$$C = \text{Cl}_2(\pi/3) \quad (46)$$

The log-sine integral is defined by

$$\text{Ls}_3(\theta) = -\int_0^\theta d\phi \log^2 \left| 2 \sin \frac{\phi}{2} \right|. \quad (47)$$

Some numerical values are shown in Table 1 and in Figure 4, where we have used

$$g^2 = \frac{e^2}{s_W^2} = \frac{4\pi\alpha}{s_W^2} \quad (48)$$

m_H/M_W	$\Delta\rho^{(1)}$	$\Delta\rho^{(2)}$	$\Delta\rho^{(3)}$
2	-0.00078	$1.14 \cdot 10^{-6}$	$-1.33 \cdot 10^{-7}$
5	-0.0018	$7.14 \cdot 10^{-6}$	$-5.20 \cdot 10^{-6}$
6	-0.0020	0.000010	-0.000011
7	-0.0022	0.000014	-0.000020
8	-0.0024	0.000018	-0.000034
9	-0.0025	0.000023	-0.000055
10	-0.0026	0.000029	-0.000083
15	-0.0031	0.000064	-0.00042
20	-0.0034	0.00011	-0.0013
25	-0.0036	0.00018	-0.0032
26	-0.0037	0.00019	-0.0038
27	-0.0037	0.00021	-0.0044
28	-0.0038	0.00022	-0.0051
29	-0.0038	0.00024	-0.0059
30	-0.0038	0.00026	-0.0067

← 500 GeV

← 2 TeV

Table 1: Corrections to ρ as a function of m_H/M_W

M(minimal) N(on) M(minimal) S(standard) Model)

with: T. Binotto

Stealth model

$$L = -\partial_\mu \phi^+ \partial_\mu \phi^- - \lambda (\phi^+ \phi^- - v^2/2)^2$$

$$-\frac{1}{2} \partial_\mu \vec{\phi} \partial_\mu \vec{\phi} - \frac{1}{2} m^2 \vec{\phi}^2 - \frac{\kappa}{8N} (\vec{\phi})^2 - \frac{\omega}{2\sqrt{N}} \vec{\phi}^2 \phi^+ \phi^-$$

$\vec{\phi}$ N scalar real fields; singlets under $SU(3) \times SU(2) \times U(1)$

$O(N)$ -symmetry, renormalizable, few extra parameters

$$\langle \vec{\phi} \rangle = 0 \quad \langle \phi \rangle = v \neq 0$$



$$\Gamma_H = \frac{\omega^2}{64\pi^2} \frac{v^2}{m_H}$$

ω can be large

$N \rightarrow \infty$ possibility non-perturbative $1/N$ -expansion

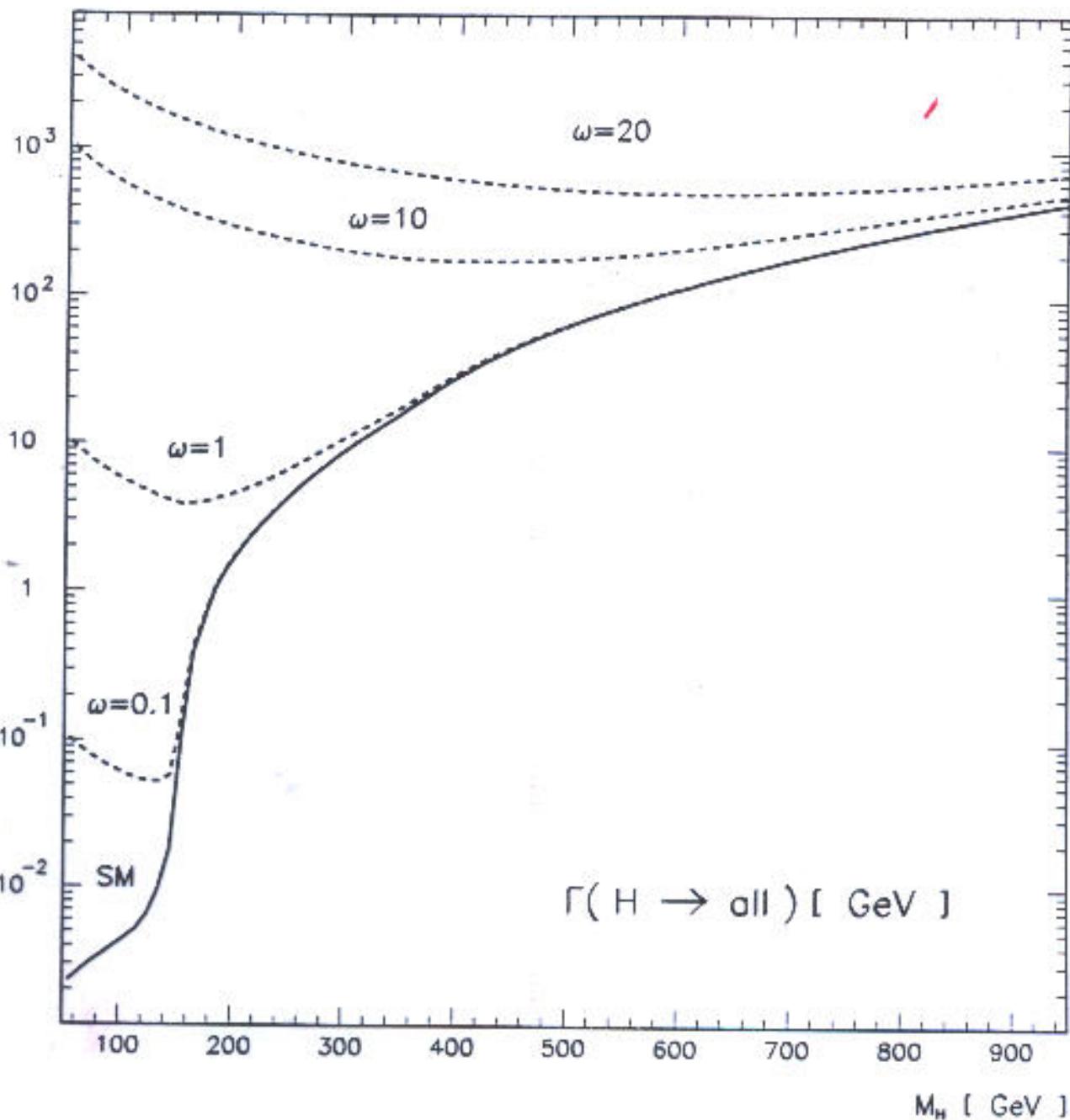
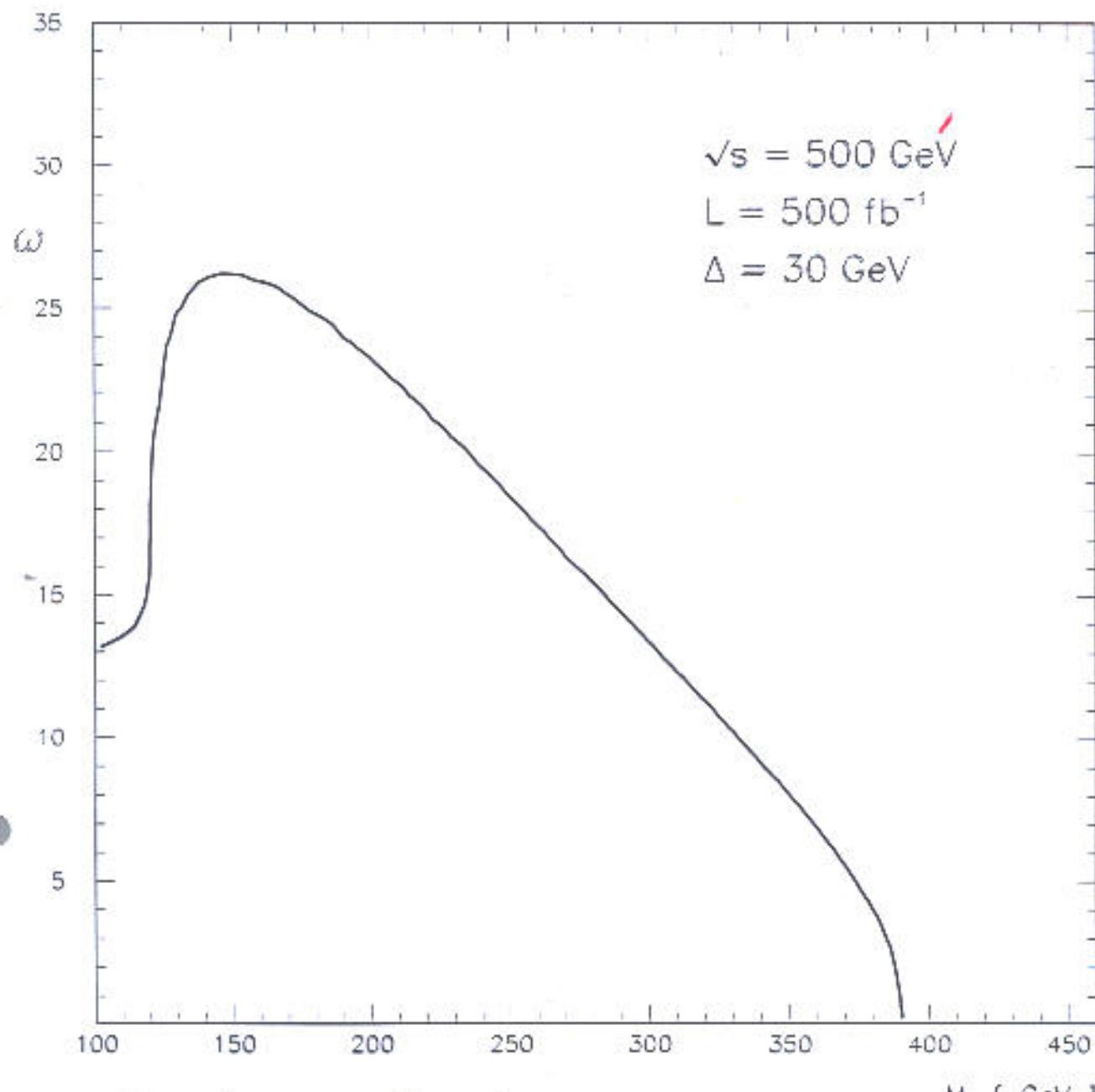


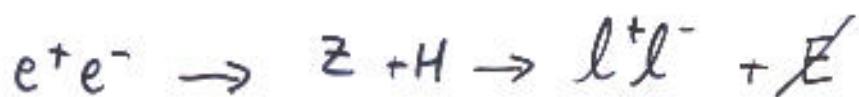
Figure 1: *Higgs width in comparison with the Standard Model.*

~~TESLA~~ ILC



Exclusion limit at TESLA

$$m_H - \Delta < E < m_H + \Delta$$



Phenomenology

ω large $\rightarrow \Gamma_H$ large

Branching ratio $\sim 100\%$ invisible

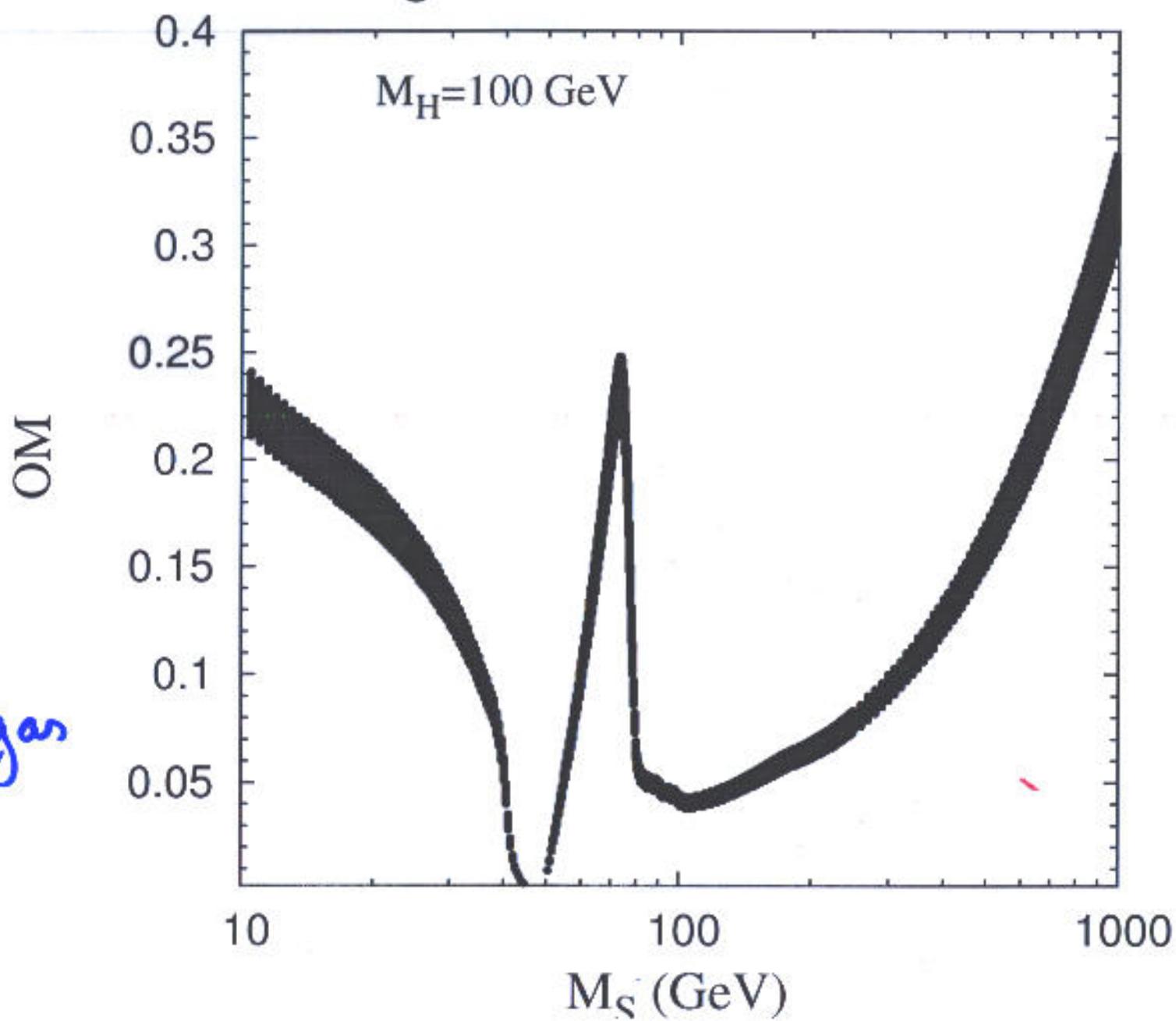
No signal at the LHC, only an enhancement over the background. One needs a very precise knowledge of the background, only possible at e^+e^- machines.

What are the gions \vec{q} ?

Weak interactions with ordinary matter
possible self-interactions

$\vec{q} = \text{Dark Matter?}$

Region $0.092 < \Omega h^2 < 0.118$



Extended standard model (with A. Hill)[†]

Higgs-sector

$$\mathcal{L} = -\frac{1}{2} (\partial_\mu \phi)^+ (\partial^\mu \phi^-) - \frac{\lambda_1}{\phi} (\phi^+ \phi^- - f_1^2)^2 - \frac{1}{2} (\partial_\mu x)^2 - \frac{\lambda_2}{\phi} (x f_2^+ - \phi^+ \phi^-)^2$$

$$M_w = \frac{g f_1}{2}$$

$$m_\pm^2 = \frac{1}{2} (\lambda_2 f_2^2 + \lambda_3 f_1^2) \pm \left\{ \lambda_2^2 f_1^2 f_2^2 + \frac{1}{4} (\lambda_2 f_2^2 - \lambda_3 f_1^2)^2 \right\}^{1/2}$$

$$\sigma - \sigma \text{ ---} = \frac{\alpha}{k^2 + m_+^2} + \frac{1-\alpha}{k^2 + m_-^2}$$

$$X - \sigma \text{ -----} = \gamma \left(\frac{1}{k^2 + m_+^2} - \frac{1}{k^2 + m_-^2} \right)$$

$$X - X \text{ ---} = \frac{1-\alpha}{k^2 + m_+^2} + \frac{\alpha}{k^2 + m_-^2}$$

$$\alpha = \frac{m_+^2 - \lambda_2 f_2^2}{m_+^2 - m_-^2} \quad 0 \leq \alpha \leq 1$$

$$\gamma = \frac{\lambda_2 f_1 f_2}{m_+^2 - m_-^2}$$

The generalization to

more fields is now

straight forward,

n Higgses H_i

with couplings

$- g_i$ with $\sum g_i^2 = g_{\text{SM}}^2$

which can be generalized

to a continuum.

$$\int g(s) ds = 1$$

General model gives
arbitrary line shape
with arbitrary invisible width
Possibilities

- 1^o Visible peak of Standard model
- 2^o Completely invisible decay
- 3^o Spread out Higgs
- 4^o Singlets too heavy for Higgs to decay into

Special Case with S. Dilcher

Higher dimensional Singlet

Few Parameters ! (Heidi models)

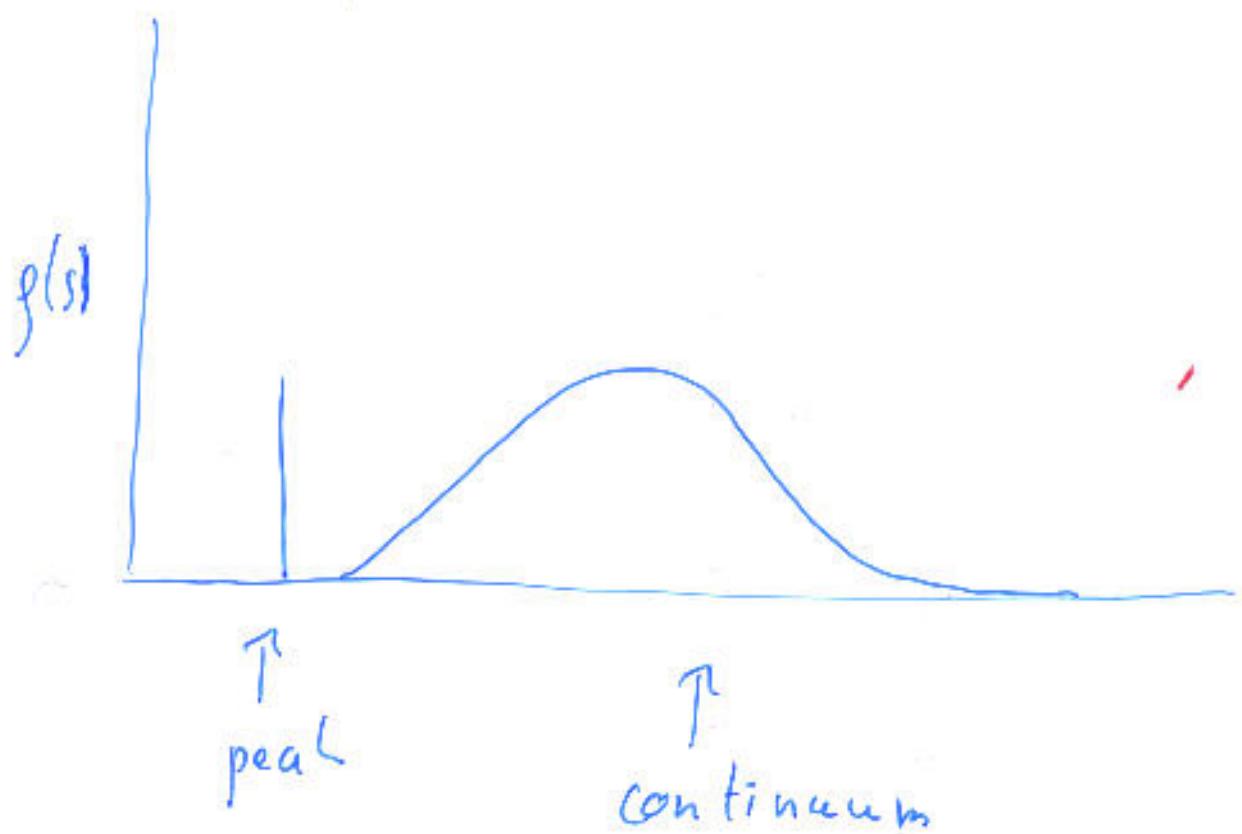
Higgs Propagator:

$$\left(q^2 + M^2 - \mu^{d-d} (q^2 + m^2)^{\frac{d-6}{2}} \right)^{-1}$$

This is possible up to $d=6$
while

$H \phi^+ \phi$ is Superrenormalizable
in $d=4$

Spectrum looks like



what does LEP 200 say?

LEP₂ Higgs Search

1° Nothing below 95 GeV

2° 2.3 σ peak $\sim 98 \text{ GeV}$

3° 1.7 σ peak $\sim 115 \text{ GeV}$

4° LL for background lower than
expected for $s^{\frac{1}{2}} > 100 \text{ GeV}$

Interpretation

$$m_H > 114.4 \text{ GeV}$$

Impose conditions

$$g_5 \text{ GeV} < m_{\text{peak}} < 101 \text{ GeV}$$

$$0.056 < \frac{g^2 g \delta}{g^2_{SM}} < 0.144$$

$$\frac{\int_{(110)^2} \rho(s) ds}{(100)^2} < 30\%$$

$$\frac{\int_{(110)^2} \rho(s) ds}{(120)^2} > 30\%$$

$$d = 5$$

$$95 \text{ GeV} < m < 101 \text{ GeV}$$

$$111 \text{ GeV} < M < 121 \text{ GeV}$$

$$26 \text{ GeV} < \mu < 49 \text{ GeV}$$

fit always possible

$$d = 6$$

$$95 \text{ GeV} < m < 101 \text{ GeV}$$

$$106 \text{ GeV} < M < 111 \text{ GeV}$$

$$22 \text{ GeV} < \mu < 27 \text{ GeV}$$

only possible in a restricted range

Conclusion

No Higgs at the LHC
(*vis?*)

caveat: significance not clear

Data were not analyzed
with this type of model in mind

- 1º) philosophical argument
- 2º) plausibility argument
- 3º) cosmological indications
- 4º) experimental data
- 5º) simplicity
- 6º) consistency at the quantum level
- 7º) a prediction that can be refuted

So this is a theory, not a scenario

Implications for ILC

1) Higgs mass spectrum

Recoil mass

good $\Delta E/E$ $\Delta p_T/p_T$

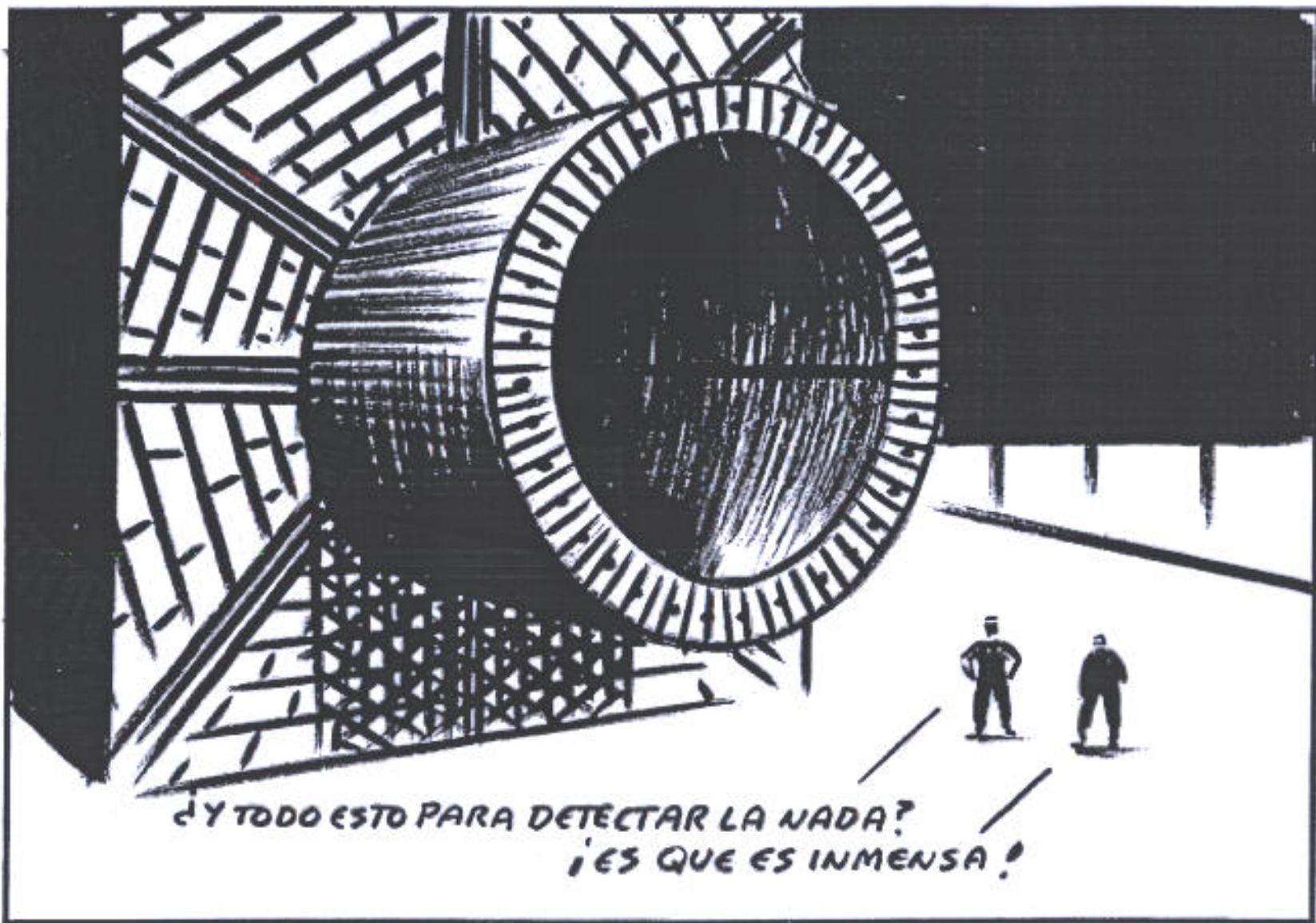
2) measurement of invisible BR function

vertex detectors

3) spectral measurement

precision measurements of energy and
luminosity

? is beam Strahlung the limiting
factor on measuring the line-shape



elroto@inicia.es