The extended Hill model on the occasion of Prof. Veltman's 80^{th} birthday

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Questions discussed with Tini.

- Can the Higgs be strongly interacting?
- How would you see this, for instance at the LHC?
- Was LEP's energy large enough?
- Should one build a linear e^+e^- collider?

Continuation from Tini's 60^{th} birthday.

Extended standard model (with A. Hill)†.

Higgs Sector

$$\mathcal{L} = -\frac{1}{2}(D_\mu\Phi)^\dagger(D_\mu\Phi) - \lambda_1/8(\Phi^\dagger\Phi - f_1^2)^2 - \frac{1}{2}(\partial_\mu H)^2 - \frac{\lambda_2}{8}(2f_2 H - \Phi^\dagger\Phi)^2$$

N.B. no H^4 coupling: pure mixing model.
Renormalizable !!

Two Higgses with reduced couplings

$$D_{HH}(k^2) = \frac{sin^2\beta}{k^2 + m_+^2} + \frac{cos^2\beta}{k^2 + m_-^2}$$

This is sufficient to study Higgs signals (interaction basis).

The generalization to more fields is straightforward.

n Higgses H_i with couplings g_i.

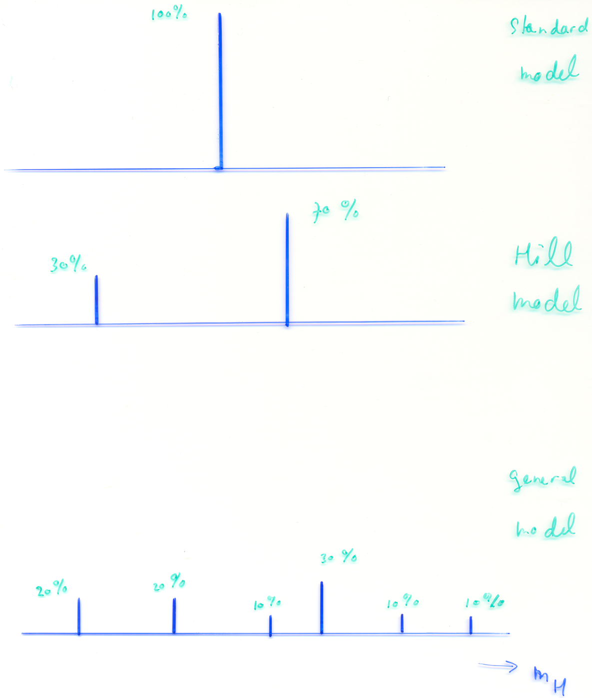
Sum rule:

$$\Sigma g_i^2 = g_{Standard\ model}^2$$

This can be generalized to a continuum.

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

Källén-Lehmann density.


100%
Standard model
70 %
30%
Hill model
general model
30 %
20%
20 %
10 %
10 %
10 %
m_H

HEIDI Models (with S. Dilcher and B. Pulice̜)

Higher dimensional singlet $\Rightarrow$ Few Parameters !

In terms of the modes H_i the Lagrangian is the following:

$$\begin{aligned} L &= -\frac{1}{2} D_\mu \Phi^\dagger D_\mu \Phi - \frac{M_0^2}{4} \Phi^\dagger \Phi - \frac{\lambda}{8} (\Phi^\dagger \Phi)^2 \\ &- \frac{1}{2} \sum (\partial_\mu H_k)^2 - \sum \frac{m_k^2}{2} H_k^2 \\ &- \frac{g}{2} \Phi^\dagger \Phi \sum H_k - \frac{\zeta}{2} \sum H_i H_j \end{aligned}$$

$m_k^2 = m^2 + m_\gamma^2 \, \vec{k}^2$, where $\vec{k}$ is a γ-dimensional vector, $m_\gamma = 2\pi/L$ and m a d-dimensional mass term for the field H.

$$S = \int d^{4+\gamma} x \prod_{i=1}^{\gamma} \delta(x_{4+i}) \left(g_B H(x) \Phi^\dagger \Phi - \zeta_B H(x) H(x) \right)$$

Propagator

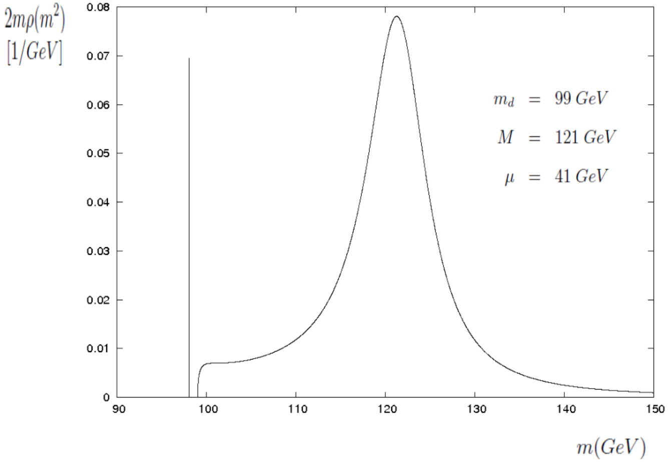
$$D_{HH}(q^2) = \left(q^2 + M^2 - \frac{\mu^{8-d}}{(q^2+m^2)^{\frac{6-d}{2}} \pm \nu^{6-d}} \right)^{-1}$$

This is renormalizable up to 6 dimensions, while

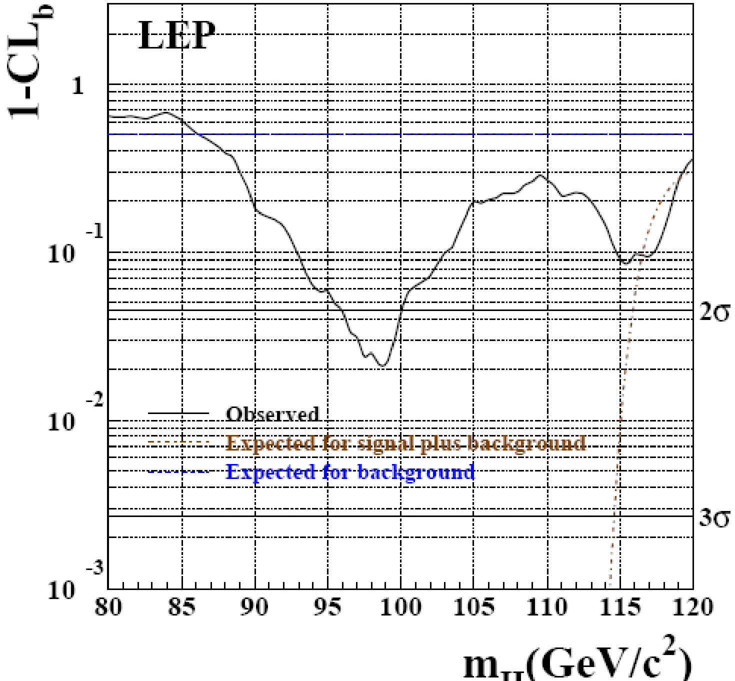
$$H\Phi^\dagger\Phi$$

is superrenormalizable in four dimensions

Corresponding Källén-Lehmann spectral density:
zero, one or two peaks plus continuum



$2m\rho(m^2)$
$[1/GeV]$
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
90
100
110
120
130
140
150
$m_d = 99\,GeV$
$M = 121\,GeV$
$\mu = 41\,GeV$
$m(GeV)$



LEP
1-CL_b
1
10^-1
10^-2
10^-3
2σ
3σ
Observed
Expected for signal plus background
Expected for background
80
85
90
95
100
105
110
115
120
m_H(GeV/c^2)

Interpretation of the data (one peak plus continuum).

- nothing below 95 GeV
- 2.3 sigma at 98 GeV
- 1.7 sigma at 115 GeV
- above 100 GeV above the background over the whole range

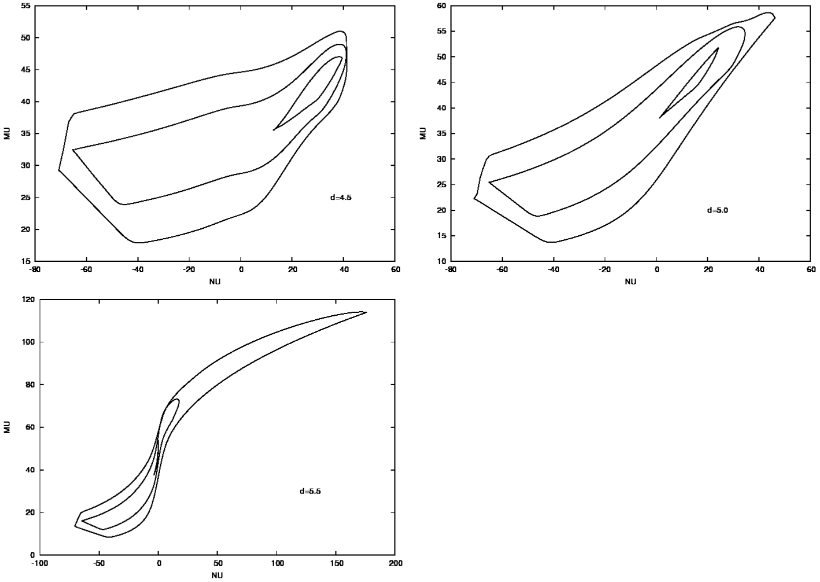
Impose conditions.

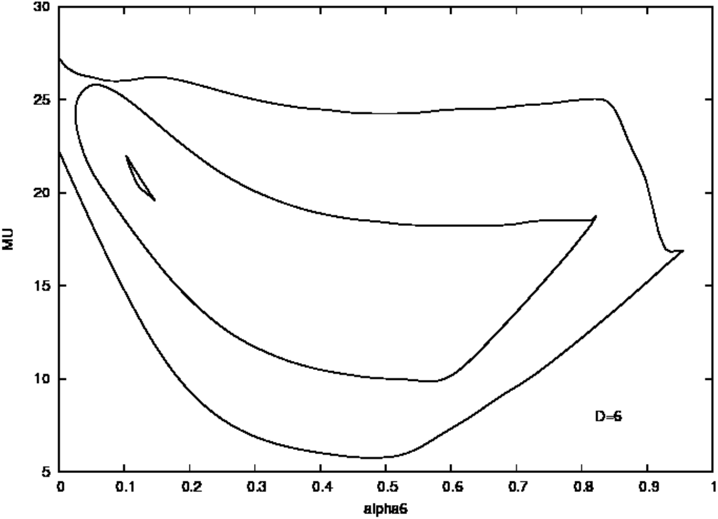
$$95\,GeV < m_{peak} < 101\,GeV$$

$$0.056 < g_{98}^2/g^2SM < 0.144$$

$$\int_{(100)^2}^{(110)^2} \rho(s)ds < 0.3$$

$$\int_{(110)^2}^{(120)^2} \rho(s)ds > 0.3$$


MU
NU
d=4.5
-80
-60
-40
-20
0
20
40
60
15
20
25
30
35
40
45
50
55
MU
NU
d=5.0
-80
-60
-40
-20
0
20
40
60
10
15
20
25
30
35
40
45
50
55
60
MU
NU
d=5.5
-100
-50
0
50
100
150
200
0
20
40
60
80
100
120



$$D_{HH}(q^2) = \left(q^2 + M^2 + \mu^2 \frac{\log((q^2+m^2)/m^2)}{1+\alpha_6 \log((q^2+m^2)/m^2)} \right)^{-1}$$

Conclusion

- The Higgs field has been found at LEP-200.
- Its properties are consistent with the electroweak precision data.
- A dark matter candidate can be included.
- The LHC will see no Higgs signal.

Caveats

Significance roughly 3.3 sigma but uncertain.
The data were not analyzed with this type of model in mind.

In the case of two peaks, the reduced peak at $115 GeV$ could possibly be seen with the design luminosity and energy of the LHC.

Theory or scenario ?

- philosophical argument
- plausibility argument
- cosmological indications
- experimental support
- simplicity
- consistency at the quantum level
- a prediction that can be refuted

So this is a theory, not a scenario !

Questions discussed with Tini.

- Can the Higgs be strongly interacting?
  YES.
- How would you see this, for instance at the LHC?
  PROBABLY NOT AT ALL.
- Was LEP's energy large enough?
  NO.
- Should one build a linear e^+e^- collider?
  MAYBE.

Questions for the ILC

Obviously a lepton collider is needed, but how well can one do?

$$e^+e^- \to Z \quad H.$$

Measurement of line-shape and invisible decay BR's.

- Energy about 250-300 GeV
- High precision
- Theory: benchmark models
- Beam Strahlung: machine
- Resolution: detector
- Unfolding: analysis