ELECTROWEAK VACUUM

Lecture 2: Experimental Precision Data and Higgs data

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Outline

The outline of Lecture 2 is

Experimental Data

- Standard Model observables
- Oblique corrections
- The ρ parameter
- $STU - \epsilon$ formalism
- $Zb\bar{b}$ coupling
- Indirect constraints on the Higgs mass
- Higgs discovery
  - ATLAS
  - CMS
- Conclusion

Standard Model observables

- Observables are written with a hat on top of them
- Some observables are
  - $\hat{\alpha}$ (from Thomson limit),
  - $\hat{G}_F$ (from muon decay),
  - $\hat{m}_Z$ (Z boson mass),
  - $\hat{m}_W$ (W boson mass),
  - $\hat{\Gamma}_{l^+l^-}$ (leptonic partial width of the Z boson), and
  - $\hat{s}^2_{\rm eff}$ (effective $\sin^2\theta_W$)
- The value of $\hat{s}^2_{\rm eff}$ is defined to be the all-orders rewriting of $\hat{A}_{LR}$, $(f = e)$ as

$$\hat{A}_{LR} = \frac{\Gamma(Z \to f_L\bar{f}_L) - \Gamma(Z \to f_R\bar{f}_R)}{\Gamma(Z \to f_L\bar{f}_L) + \Gamma(Z \to f_R\bar{f}_R)} = \frac{g_L^2 - g_R^2}{g_L^2 + g_R^2}$$

$$\equiv \frac{(1/2 - \hat{s}^2_{\rm eff})^2 - \hat{s}^4_{\rm eff}}{(1/2 - \hat{s}^2_{\rm eff})^2 + \hat{s}^4_{\rm eff}}$$

- At tree level we need only three lagrangian parameters to compute the six observables listed above. They are v (the Higgs vacuum expectation value) and
  - g ($SU(2)$ gauge coupling)
  - g' ($U(1)_Y$ gauge coupling)
- We trade these two parameters for an equivalent set
  - e (the electric charge): $g = e/s$, $g' = e/c$
  - $s(= \sin\theta_W)$
- The observables can be expressed at tree-level as

Tree-level observables and experimental values

- $\hat{\alpha} = \frac{e^2}{4\pi}$; $\quad \hat{\alpha}^{exp} = 1/137.0359895(61)$
- $\hat{G}_F = \frac{1}{\sqrt{2}v^2}$; $\quad \hat{G}_F^{exp} = 1.16639(1) \times 10^{-5}\,\mathrm{GeV}^{-2}$
- $\hat{m}_Z^2 = \frac{e^2 v^2}{4s^2c^2}$; $\quad \hat{m}_Z^{exp} = 91.1876 \pm 0.0021$ GeV
- $\hat{m}_W^2 = \frac{e^2 v^2}{4s^2}$; $\quad \hat{m}_W^{exp} = 80.428 \pm 0.039$ GeV
- $\hat{s}_{\rm eff}^2 = s^2$; $\quad (\hat{s}_{\rm eff}^2)^{exp} = 0.23150 \pm 0.00016$
- $\hat{\Gamma}_{l^+l^-} = \frac{v}{96\pi}\frac{e^3}{s^3c^3}\left[\left(-\frac{1}{2} + 2s^2\right)^2 + \frac{1}{4}\right]$;
  $(\hat{\Gamma}_{l^+l^-})^{exp} = 83.984 \pm 0.086\,\mathrm{MeV}$

- The real question that a theory must answer is, *Can we reproduce all experimental results with suitable choices of our input parameters?*
- We have a set of observables $\hat{\mathcal{O}}_i^{\rm expt}$ with uncertainties $\Delta\hat{\mathcal{O}}_i^{\rm expt}$. The theory makes predictions $\mathcal{O}_i^{\rm th}$ for the observables that depend on the lagrangian parameters
- We find the best possible choices of the lagrangian parameters that fit the data by e.g. minimizing the χ^2 function (i sums over the observables)

$$\chi^2(e,s,v)=\sum_i \frac{(\hat{\mathcal{O}}_i^{\rm expt}-\mathcal{O}_i^{\rm th}(e,s,v))^2}{(\Delta\hat{\mathcal{O}}_i^{\rm expt})^2}$$

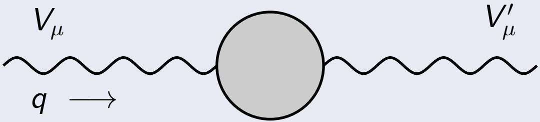
- The predictions of $\hat{m}_W$, $\hat{s}^2_{\rm eff}$ and $\hat{\Gamma}_{l^+l^-}$ in this particular tree-level procedure are approximately 15σ, 120σ and 10σ off from their experimentally measured values
- Should we conclude that the theory is not compatible with experiment?
- We must go to higher-order in the coupling constants to truly test the viability of the SM

Oblique corrections

- They are corrections that arise only from the self-energy of the γ, $W^{\pm}$, and Z vector bosons
- A complete analysis with all corrections explicitly computed is much more complicated but it is similar conceptually
- In BSM theories it is most common that the non-oblique corrections have a small effect compared to the oblique corrections. This is generally true in supersymmetry, with the notable exception of the $Z \to b\bar{b}$ coupling
- One main reason for the dominance of oblique over non-oblique corrections is that any charged field couples to vector bosons, whereas usually only one or two particles in a theory couple to a specific fermion species
- The sum over all contributors in self-energies wins out over the one or two diagrams that couple to an individual final state fermion

- The one-loop corrections to the vector boson self-energies

Oblique corrections



$$i[\Pi_{VV'}(q^2)g^{\mu\nu} - \Delta_{VV'}(q^2)q^\mu q^\nu]$$

- Only the $\Pi_{VV'}$ piece of the self-energies since the q^μ part of the second term is coupled with a light-fermion current and is zero by the Dirac equation

$$q^\mu J_\mu^{\text{light fermion}} \to \bar{f}\gamma^\mu q_\mu f \to \bar{f} m f \to 0.$$

- The way the self-energies are defined, they add to the vector boson masses by convention:

$$m_V^2 \to m_V^2 + \Pi_{VV}(q^2 = m_V^2)$$

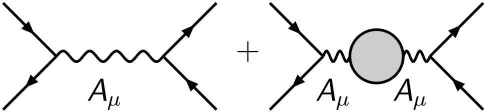
- The correction of Z and W masses is

Z and W masses

$$(\hat{m}_Z^2)^{th} = \frac{e^2 v^2}{4 s^2 c^2} + \Pi_{ZZ}(m_Z^2)$$

$$(\hat{m}_W^2)^{th} = \frac{e^2 v^2}{4 s^2} + \Pi_{WW}(m_W^2)$$

- The theory prediction for $\hat{\alpha}$ comes from

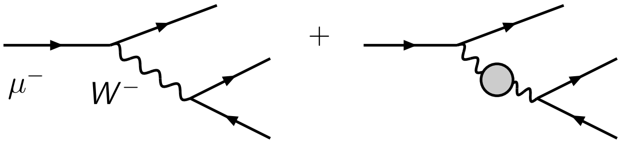


$$-i\, \frac{4\pi\hat{\alpha}}{q^2}\bigg|_{q^2\to 0} = \frac{-ie^2}{q^2}\left[1 + \frac{\Pi_{\gamma\gamma}(q^2)}{q^2}\right]_{q^2\to 0}$$

$\hat{\alpha}$

$$(\hat{\alpha})^{th} = \frac{e^2}{4\pi}\left(1 + \Pi'_{\gamma\gamma}(0)\right)$$

- $\hat{G}_F$ is computed from the lifetime of the muon



$\hat{G}_F$

$$\frac{(\hat{G}_F)^{th}}{\sqrt{2}} = \frac{g^2}{8m_W^2}\left[1 + i\Pi_{WW}(q^2)\left(\frac{-i}{q^2 - m_W^2}\right)\right]_{q\to 0}$$

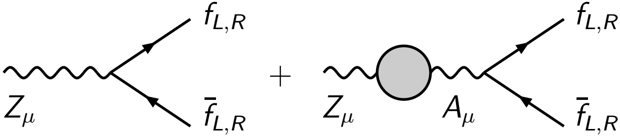
$$= \frac{1}{2v^2}\left[1 - \frac{\Pi_{WW}(0)}{m_W^2}\right]$$

- The definition of $\hat{s}^2_{\text{eff}}$ is chosen such that observable $\hat{A}^{\ell}_{LR}$ is written in terms of $\hat{s}^2_{\text{eff}}$ using the tree-level expression above with $s^2 \to \hat{s}^2_{\text{eff}}$. This is an unambiguous definition

- The observable associated with $\hat{s}^2_{\rm eff}$ requires correcting

$$g_L = \frac{e}{sc}(T^3 - Qs^2) \quad \text{and} \quad g_R = -\frac{-eQs^2}{sc}$$

- We can neglect all Π_{ZZ} contributions since they will only affect the overall factor of g_L and g_R which cancels
- The $Z - A$ mixing self-energy does contribute

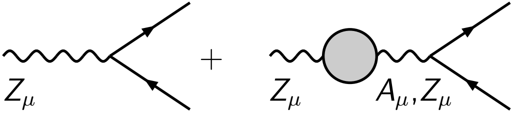


- g_L and g_R expressions are the tree-level expressions except $s^2 \to s^2 - sc\Pi_{\gamma Z}(m_Z^2)/m_Z^2$ in the numerator

$\hat{s}^2_{\rm eff}$

$$(\hat{s}^2_{\rm eff})^2 = s^2 - sc\frac{\Pi_{\gamma Z}(q^2 = m_Z^2)}{m_Z^2}$$

- Finally for $\hat{\Gamma}_{l^+l^-}$ the relevant diagrams are



$\hat{\Gamma}_{l^+l^-}$

$$(\hat{\Gamma}_{l^+l^-})^{th} = \frac{Z_Z}{48\pi}\frac{e^2}{s^2c^2}\hat{m}_Z\left[\left(-\frac{1}{2}+2(\hat{s}^2_{\rm eff})^{th}\right)^2+\frac{1}{4}\right]$$

$$Z_Z = 1 + \Pi'_{ZZ}(\hat{m}_Z^2)$$

- $\Pi_{\gamma Z}$ had the effect of just putting $s^2 \to (\hat{s}^2_{\rm eff})^{th}$ into the numerator
- The parameter Z_Z is a wavefunction residue piece

THE ρ PARAMETER

- The relative strength of the charged and neutral currents, $J_Z^\mu J_{\mu Z}/J^{\mu +}J_\mu^-$ can be measured by

$$\rho = \frac{m_W^2}{c_W^2 m_Z^2}$$

- It is equal to 1 in the SM. A direct consequence of the choice of the representation of the Higgs field responsible for the breaking of the electroweak symmetry
- In a model which makes use of an arbitrary number of Higgs multiplets Φ_i with isospin T_i,

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

which is also unity for an arbitrary number of doublet [as well as singlet] fields.
- This is due to the fact that in this case, the model has a custodial SU(2) global symmetry.

- The SM lagrangian has a global $SU(2)$ symmetry in the limit $g' \to 0$ and $Y^u \to Y^d$
- This symmetry appears as follows: the field H has 4 real components and in the Higgs lagrangian there is an associated $O(4)$ symmetry broken to $O(3) \simeq SU(2)$ at the electroweak breaking
- In the SM, the custodial symmetry is broken at the loop level when fermions of the same doublet have different masses and by the hypercharge group.
- One can define an effective mixing angle and its relation with the ρ parameter as

$$\bar{s}_W^2 = 1 - \frac{m_W^2}{m_Z^2} + c_W^2 \left(\frac{\Pi_{WW}(m_W^2)}{m_W^2} - \frac{\Pi_{ZZ}(m_Z^2)}{m_Z^2} \right)$$

$$\sim 1 - \frac{m_W^2}{m_Z^2} + c_W^2 \Delta\rho$$

- Because m_t is large, the contributions are approximately the same at the scale $q^2 \sim 0$ or $q^2 \sim m_V^2$; in addition the light fermion contributions to Π_{WW} and Π_{ZZ} almost cancel in the difference ($\sim \log m_W/m_Z$)
- One usually writes the correction to the ρ parameter as

ρ parameter

$$\rho = \frac{1}{1-\Delta\rho} \quad , \quad \Delta\rho = \frac{\Pi_{WW}(0)}{m_W^2} - \frac{\Pi_{ZZ}(0)}{m_Z^2}$$

- The large mass splitting between the top and bottom quark masses breaks the custodial $SU(2)$ symmetry and generates a contribution which grows as the top mass squared

One-loop top quark contribution to the ρ parameter

$$\Delta\rho = \frac{3 G_\mu m_t^2}{8\sqrt{2}\pi^2} \sim 0.01$$

- Exercise: compute $\Pi_{VV}(q^2)$ from fermion loops

- At the one–loop level the Higgs boson contributes

One-loop Higgs contribution to the ρ parameter

$$(\Delta\rho)^{\rm Higgs} = -\frac{3G_\mu m_W^2}{8\sqrt{2}\pi^2}\, f\left(\frac{m_H^2}{m_Z^2}\right)$$

$$f(x) = x\left[\frac{\ln c_W^2 - \ln x}{c_W^2 - x} + \frac{\ln x}{c_W^2(1-x)}\right]$$

- The contribution vanishes in the limit $s_W^2 \to 0$ or $m_W \to m_Z$, i.e. when $g' \to 0$
- For a very light Higgs boson the correction vanishes

$$(\Delta\rho)^{\rm Higgs} \to 0 \quad \text{for } m_H \ll m_W$$

- For a heavy Higgs boson

$$(\Delta\rho)^{\rm Higgs} \sim -\frac{3G_\mu m_W^2}{8\sqrt{2}\pi^2}\,\frac{s_W^2}{c_W^2}\log\frac{m_H^2}{m_W^2}$$

- The logarithmic dependence is the “Veltman screening theorem”

STU-ϵ formalism

- It is convenient to parametrize the radiative corrections to electroweak observables in such a way that the contributions due to many kinds of New Physics beyond the SM are easily implemented and confronted with the experimental data
- If one assumes that the symmetry group of New Physics is still $SU(3)_C \times SU(2)_L \times U(1)_Y$ and that it couples only weakly to light fermions so that one can neglect all the "direct" vertex and box corrections, one needs to consider only the oblique corrections, that is, the ones affecting the γ, Z, W two–point functions and the $Z\gamma$ mixing
- If the scale of the New Physics is much higher than m_Z, one can expand the complicated functions of the momentum transfer Q^2 around zero, and keep only the constant and the linear $Q^2/M^2_{\rm NP}$ terms of the series which have very simple expressions in general

- The New Physics contributions can then be expressed in terms of six functions

Functions parametrizing New Physics

$$\Pi'_{\gamma\gamma}(0),\ \Pi'_{Z\gamma}(0),\ \Pi_{ZZ}(0),\ \Pi'_{ZZ}(0),\ \Pi_{WW}(0),\ \Pi'_{WW}(0)$$

QED Ward identities $\Rightarrow \Pi_{\gamma\gamma}(0) = \Pi_{Z\gamma}(0) = 0$

$$\mathcal{L}_{new} = -\frac{\Pi'_{\gamma\gamma}(0)}{4} F_{\mu\nu}F^{\mu\nu} - \frac{\Pi'_{WW}(0)}{2} W_{\mu\nu}W^{\mu\nu} - \frac{\Pi'_{ZZ}(0)}{4} Z_{\mu\nu}Z^{\mu\nu}$$

$$-\frac{\Pi'_{\gamma Z}(0)}{2} F_{\mu\nu}Z^{\mu\nu} - \Pi_{WW}(0) W^+_\mu W^{\mu -} - \frac{\Pi_{ZZ}(0)}{2} Z_\mu Z^\mu$$

- Three of these functions will be absorbed in the renormalization of the three input parameters α, G_μ and M_Z

- This leaves three variables which one can choose as being ultraviolet finite and related to physical observables
- A popular choice of the three independent variables is the STU linear combinations of self–energies introduced by Peskin and Takeuchi [1]

STU parameters

$$\alpha S =$$

$$4 s_W^2 c_W^2 \left[\Pi'_{ZZ}(0) - (c_W^2 - s_W^2)/(s_W c_W)\cdot \Pi'_{Z\gamma}(0) - \Pi'_{\gamma\gamma}(0)\right]$$

$$\alpha T = \Pi_{WW}(0)/m_W^2 - \Pi_{ZZ}(0)/m_Z^2$$

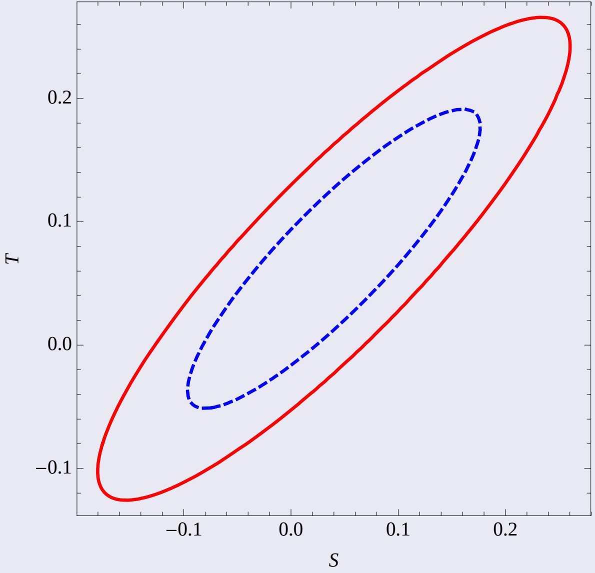
$$\alpha U =$$

$$4 s_W^2 \left[\Pi'_{WW}(0) - c_W^2 \Pi'_{ZZ}(0) - 2 s_W c_W \Pi'_{Z\gamma}(0) - s_W^2 \Pi'_{\gamma\gamma}(0)\right]$$

- The variable αT is simply the shift of the ρ parameter due to the New Physics, $\alpha T = 1 - \rho - \Delta\rho|_{\rm SM}$

[1] M. Peskin, T. Takeuchi, PRD 46 (1992) 381

The fit to experimental data



68% (95%) CL regions

- Another parametrization of the radiative corrections, the ϵ approach of Altarelli and Barbieri is more directly related to the precision electroweak observables
- The three variables which parametrize the oblique corrections are defined in such a way that they are zero in the approximation where only SM effects at the tree–level, as well as the pure QED and QCD corrections, are taken into account
- Defining Δr_W and Δk as

$$m_W^2/m_Z^2\left(1-m_W^2/m_Z^2\right)=s_0^2c_0^2(1-\Delta r_W)$$

$$\sin^2\theta_{\rm eff}^{\rm lep}=(1+\Delta k)s_0^2$$

with

$$s_0^2c_0^2=\pi\alpha(m_Z)/(\sqrt{2}G_\mu m_Z^2)$$

- The variables defined by Altarelli and Barbieri are

ϵ parameters

$$\epsilon_1 = \Delta\rho$$

$$\epsilon_2 = c_0^2\Delta\rho + \frac{s_0^2}{c_0^2 - s_0^2}\Delta r_W - 2s_0^2\Delta k$$

$$\epsilon_3 = c_0^2\Delta\rho + (c_0^2 - s_0^2)\Delta k, \quad \epsilon_4 = \Delta_b$$

Experimental values of ϵ parameters

$$\epsilon_1 = -0.0009 \pm 0.0008(-0.0006)$$

$$\epsilon_2 = -0.0006 \pm 0.0009(+0.0007)$$

$$\epsilon_3 = -0.0013 \pm 0.0009(-0.0001)$$

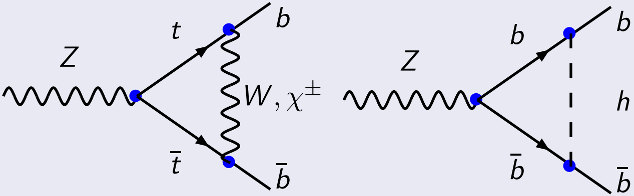
$$M_h = 117\ (300)\ GeV$$

- Δ_b is non-oblique correction to $Z \to b\bar{b}$

$Z \to b\bar{b}$ COUPLING

- In the context of precision tests, the Z boson decay into bottom quarks has a special status
  1. Because of its large mass and relatively large lifetime the b quark can be tagged and experimentally separated from light quark and gluon jets allowing an independent measurement of the $Z \to b\bar{b}$ partial decay width
  2. Large radiative corrections involving the top quark and not contained in $\Delta\rho$ appear

$Z \to b\bar{b}$ one-loop diagrams



- These corrections can be accounted for by shifting the reduced vector and axial–vector $Zb\bar{b}$ couplings by the amount

$$\hat{a}_b \to 2T_b^3(1+\Delta_b) \quad , \quad \hat{v}_b \to 2T_b^3(1+\Delta_b) - 4Q_b s_W^2$$

- For a heavy top quark, the correction can be cast into a rather simple form

$$\Delta_b = -\frac{G_\mu m_t^2}{4\sqrt{2}\pi^2} - \frac{G_\mu m_Z^2}{12\sqrt{2}\pi^2}(1+c_W^2)\log\frac{m_t^2}{m_W^2} + \cdots$$

  This correction is large being approximately of the same size as the $\Delta\rho$ correction
- The Higgs contribution

$$\Delta_b^{1-\mathrm{Higgs}} \propto \frac{G_\mu m_b^2}{4\sqrt{2}\pi^2}$$

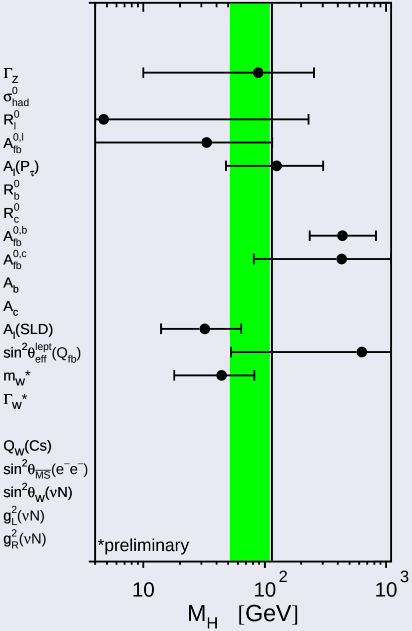
  Because the b–quark mass is very small compared to the W boson mass, $m_b^2/m_W^2 \sim 1/250$, this contribution is negligible in the SM

Indirect constraints on Higgs mass

$\alpha(m_Z), G_\mu$ and m_Z can be used as basic input parameters. Then the other observables can be predicted as a function of the Higgs mass m_H:

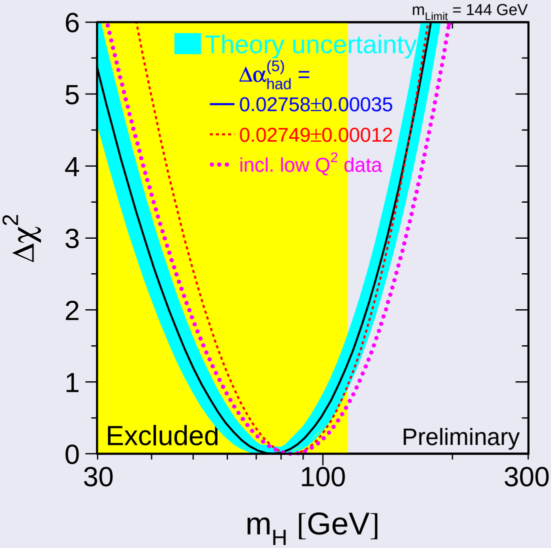
- Observables from the Z lineshape at LEP1: Γ_Z, the peak hadronic cross section $\sigma^0_{\rm had}$, $\Gamma(Z \to \ell, c, b)$ normalized to the hadronic Z decay width, $R_{\ell,c,b}$, A^f_{FB} for leptons and heavy c, b quarks, $A^\tau_{\rm pol}$
- A^f_{LR} which has been measured at the SLC as well as the left–right forward–backward asymmetries $A^{b,c}_{LR,FB}$
- m_W and Γ_W precisely measured at LEP2
- High–precision measurements at low energies
  - The ν_μ– and $\bar{\nu}_\mu$–nucleon deep–inelastic scattering cross sections
  - The parity violation in the Cesium and Thallium atoms which provide the weak charge Q_W that quantifies the coupling of the nucleus to the Z boson

Electroweak observables pull



Indirect search limit: pre-LHC

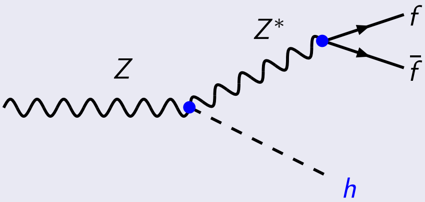
$$m_H < 144\ GeV\ 95\% C.L.$$



Higgs Discovery

- The Higgs boson has been searched for at the LEP1 experiment at $\sqrt{s} \simeq M_Z$. The dominant production mode was the Bjorken process where the on-shell Z boson decays into a real Higgs boson and an off–shell Z boson which goes into two light fermions

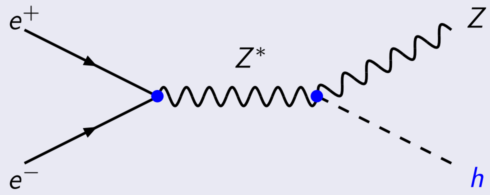
Main production mechanism for Higgs bosons at LEP1



- The Higgs boson can also be produced in the decay $Z \to H\gamma$ which occurs through triangular loops built–up by heavy fermions and the W boson

- The search for Higgs bosons was extended at LEP2 $\sqrt{s} = 209$ GeV. The dominant production process is Higgs–strahlung where the e^+e^- pair goes into an off–shell Z boson which then splits into a Higgs particle and a real Z boson

Main production mechanism for Higgs bosons at LEP2



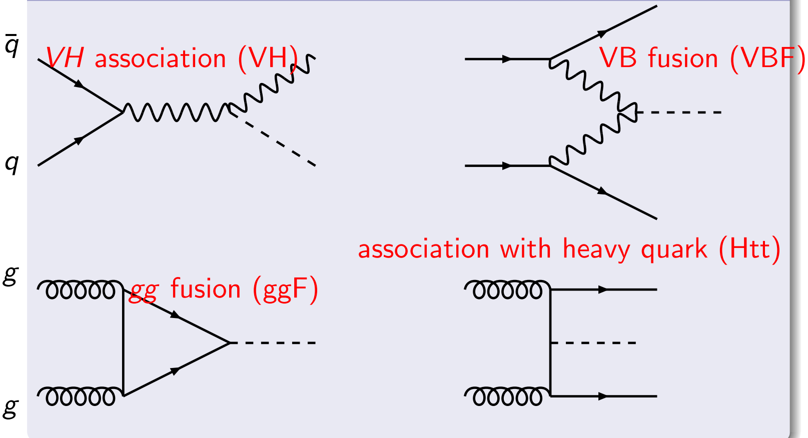
- Combining the results of the four LEP collaborations the exclusion limit

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

was established at the 95% CL

- There was a 1.7σ excess (not significant) of events for a Higgs boson mass in the vicinity of $M_H = 116$ GeV.

Higgs production at LHC



LHC (both ATLAS and CMS collaborations) have confirmed discovery of the Higgs boson with a mass

$$m_H = 125.5 \pm 0.5 \text{ GeV}$$

in the $h \to ZZ$, $h \to WW$ and $h \to \gamma\gamma$ channels

Measured observables are ratios of Higgs couplings with respect to their SM values

$$\kappa_V = \frac{g_{hVV}}{(g_{hVV})_{SM}}$$

$$\kappa_F = \frac{g_{hFF}}{(g_{hFF})_{SM}}$$

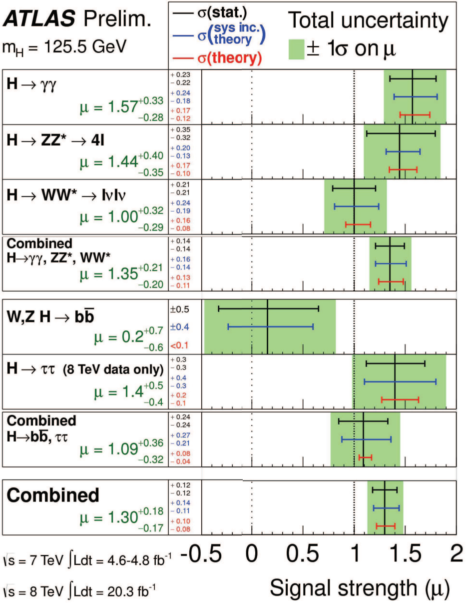
and ratios of Higgs strengths with respect to SM values

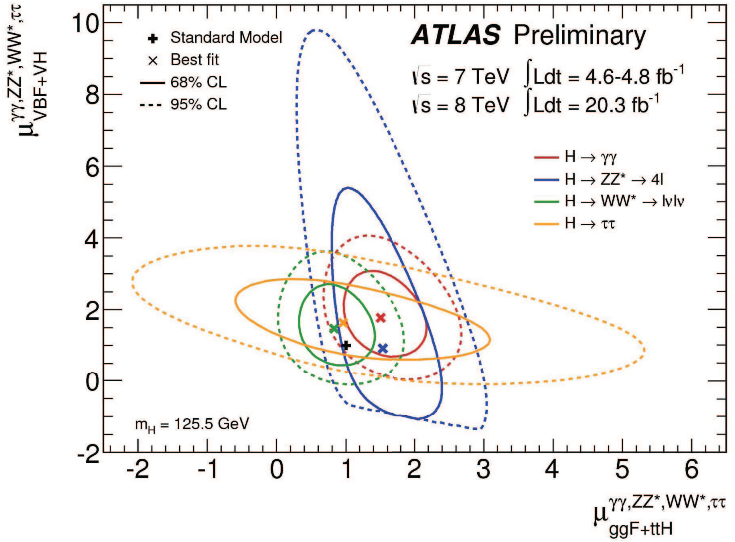
$$\mu_i^X = \frac{\sigma_i(h) \times BR(h \to X)}{\sigma_i(h)_{SM} \times BR(h \to X)_{SM}}$$

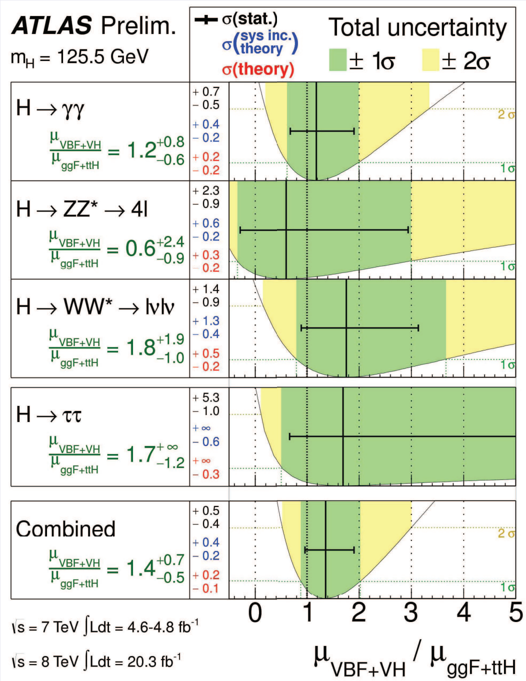
$$X = WW^*, ZZ^*, \gamma\gamma, \tau\tau, \ldots$$

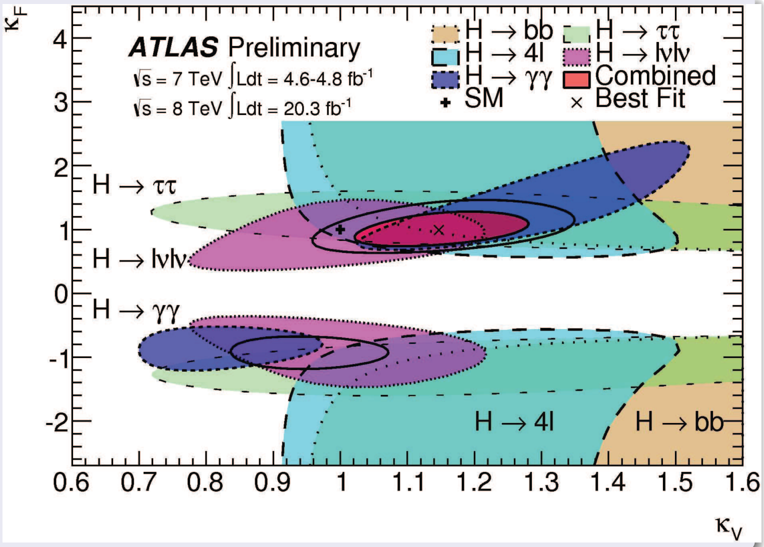
$$i = ggF, VBF, HV, Htt$$

ATLAS RESULTS

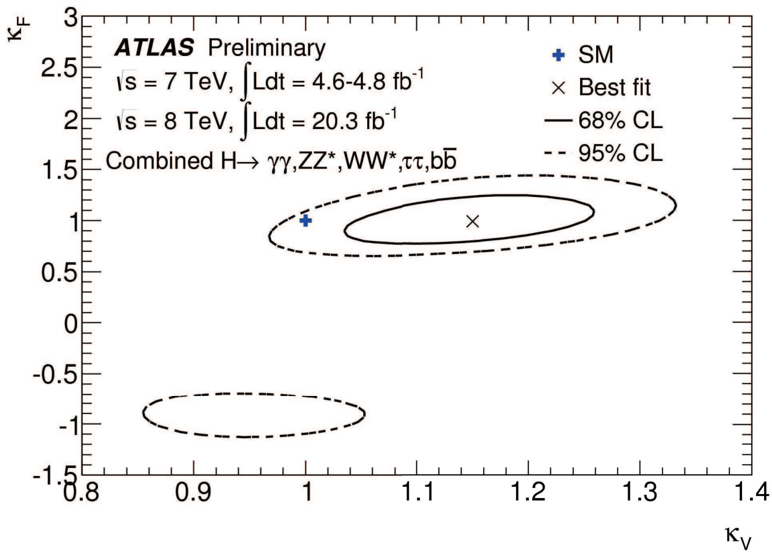



ATLAS Preliminary
$\sqrt{s}$ = 7 TeV $\int Ldt$ = 4.6-4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV $\int Ldt$ = 20.3 fb^{-1}
Standard Model
Best fit
68% CL
95% CL
$H \to \gamma\gamma$
$H \to ZZ^* \to 4l$
$H \to WW^* \to l\nu l\nu$
$H \to \tau\tau$
m_H = 125.5 GeV
$\mu^{\gamma\gamma,ZZ^*,WW^*,\tau\tau}_{VBF+VH}$
$\mu^{\gamma\gamma,ZZ^*,WW^*,\tau\tau}_{ggF+ttH}$

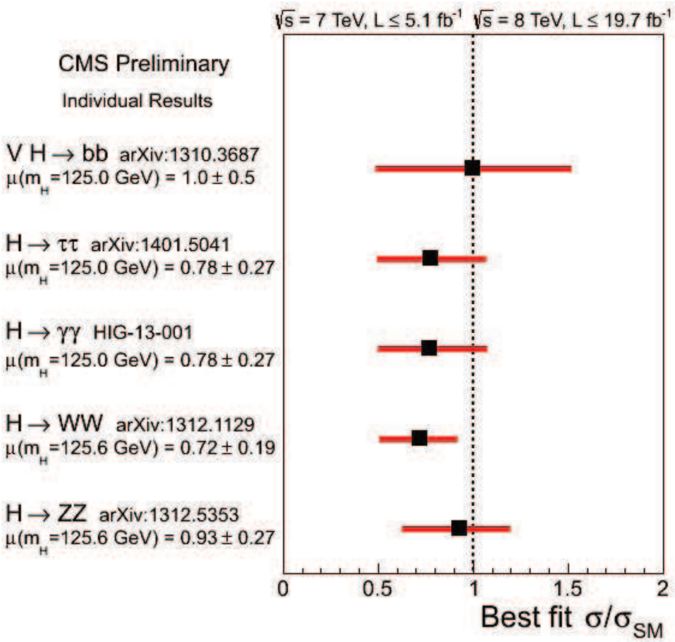

ATLAS Prelim.
m_H = 125.5 GeV
σ(stat.)
σ(sys inc. theory)
σ(theory)
Total uncertainty
± 1σ
± 2σ
H → γγ
μVBF+VH / μggF+ttH = 1.2 +0.8 −0.6
+0.7 −0.5
+0.4 −0.2
+0.2 −0.2
H → ZZ* → 4l
μVBF+VH / μggF+ttH = 0.6 +2.4 −0.9
+2.3 −0.9
+0.6 −0.2
+0.3 −0.2
H → WW* → lνlν
μVBF+VH / μggF+ttH = 1.8 +1.9 −1.0
+1.4 −0.9
+1.3 −0.4
+0.5 −0.2
H → ττ
μVBF+VH / μggF+ttH = 1.7 +∞ −1.2
+5.3 −1.0
+∞ −0.6
+∞ −0.3
Combined
μVBF+VH / μggF+ttH = 1.4 +0.7 −0.5
+0.5 −0.4
+0.4 −0.2
+0.2 −0.1
2σ
1σ
0 1 2 3 4 5
√s = 7 TeV ∫Ldt = 4.6-4.8 fb⁻¹
√s = 8 TeV ∫Ldt = 20.3 fb⁻¹
μVBF+VH / μggF+ttH

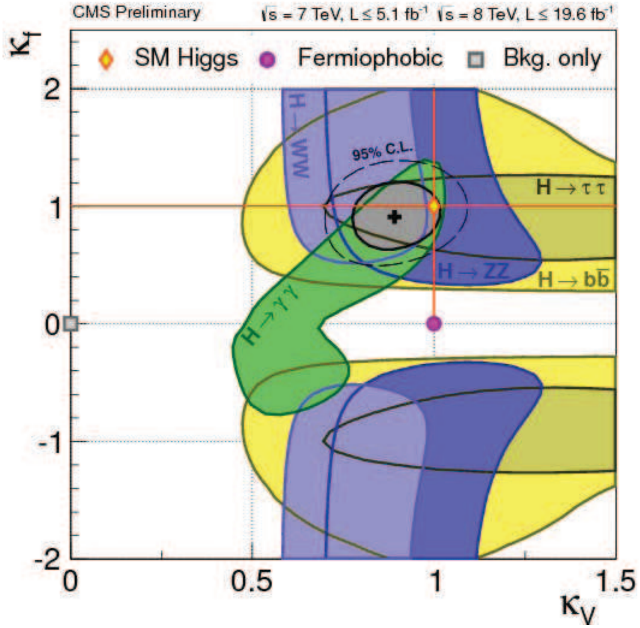


ATLAS Preliminary
√s = 7 TeV ∫Ldt = 4.6-4.8 fb-1
√s = 8 TeV ∫Ldt = 20.3 fb-1
H → bb
H → ττ
H → 4l
H → lνlν
H → γγ
Combined
SM
Best Fit
H → ττ
H → lνlν
H → γγ
H → 4l
H → bb
κF
κV
0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6
-2 -1 0 1 2 3 4


ATLAS Preliminary
√s = 7 TeV, ∫Ldt = 4.6-4.8 fb-1
√s = 8 TeV, ∫Ldt = 20.3 fb-1
Combined H→ γγ,ZZ*,WW*,ττ,bb̄
SM
Best fit
68% CL
95% CL
κF
κV
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0.8
0.9
1
1.1
1.2
1.3
1.4

CMS RESULTS


√s = 7 TeV, L ≤ 5.1 fb⁻¹ √s = 8 TeV, L ≤ 19.7 fb⁻¹
CMS Preliminary
Individual Results
V H → bb arXiv:1310.3687
μ(m_H=125.0 GeV) = 1.0 ± 0.5
H → ττ arXiv:1401.5041
μ(m_H=125.0 GeV) = 0.78 ± 0.27
H → γγ HIG-13-001
μ(m_H=125.0 GeV) = 0.78 ± 0.27
H → WW arXiv:1312.1129
μ(m_H=125.6 GeV) = 0.72 ± 0.19
H → ZZ arXiv:1312.5353
μ(m_H=125.6 GeV) = 0.93 ± 0.27
0
0.5
1
1.5
2
Best fit σ/σ_SM


CMS Preliminary
√s = 7 TeV, L ≤ 5.1 fb⁻¹ √s = 8 TeV, L ≤ 19.6 fb⁻¹
SM Higgs
Fermiophobic
Bkg. only
95% C.L.
H → WW
H → ττ
H → ZZ
H → bb̄
H → γγ
κ_f
κ_V
2
1
0
-1
-2
0
0.5
1
1.5

Conclusion

- The Higgs boson has been found with a mass $m_H = 125.5$ GeV
- This discovery has profound implications on the structure and the consistency of the theory (see Lecture 3)
- Everything seems consistent with just the SM of electroweak interactions, although...
- For the moment the accuracy of the measurement of Higgs observables is poor and there is some room for BSM (see Lecture 4)