Precision Higgs coupling measurements at the LHC through ratios of production cross sections

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Content

Introduction

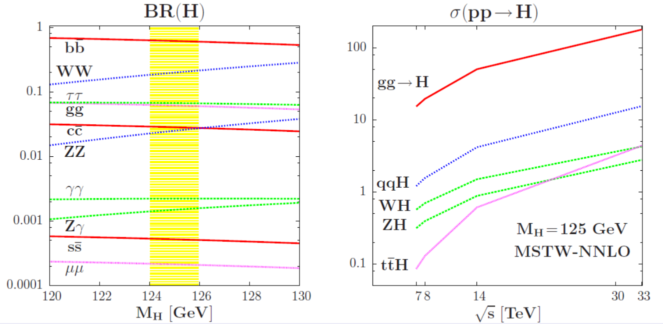
Paper

- Title: *Precision Higgs coupling measurements at the LHC through ratios of production cross sections*
- Author: Abdelhak Djouadi
- URL: arXiv:1208.3436v1

Introduction

The new Boson

- new boson at m $\approx$ 125GeV discovered by ATLAS and CMS
- next important step is the measurement of properties of the new particle (couplings to fermions and vector-bosons, self-coupling)
- the mass of 125 GeV allows a wide range of decay channels



Uncertainty

Theoretical Uncertainties

- the theoretical uncertainty on the cross section $\Delta\sigma^{theo} \approx \pm 20\%$ is already at same level as the measurements ($20 - 25\%$ for ATLAS and CMS)
- big fraction comes from scale and PDF uncertainties
- to remove the uncertainties one can use ratios of cross sections (C_{XX}) and decay branching fractions (D_{XX})

Decay Ratios D_{XX}

Definition

- the ratio is always defined against a reference channel → use decay into vector boson with the clean leptonic final states

$$D_{XX} = \frac{\sigma(gg \to H \to XX)}{\sigma(gg \to H \to VV)} = \frac{\sigma(gg \to H) \times \mathrm{BR}(H \to XX)}{\sigma(gg \to H) \times \mathrm{BR}(H \to VV)} = \frac{\Gamma(H \to XX)}{\Gamma(H \to VV)}$$

- the significant theory uncertainties cancel out
- the ration is independent of the Higgs width (no contribution from invisible decay channels)
- some experimental uncertainties also cancel out, e.g. uncertainties on luminosity and Higgs branching ratio (effect by b-quark mass measurements)

Decay Ratios D_{XX}

Possible ratio observables

$$D_{ZZ} = \frac{\sigma(gg \to H \to ZZ)}{\sigma(gg \to H \to VV)} = \frac{\Gamma(H \to ZZ)}{\Gamma(H \to VV)} = d_{ZZ}\frac{c_Z^2}{c_V^2}$$

$$D_{WW} = \frac{\sigma(gg \to H \to WW)}{\sigma(gg \to H \to VV)} = \frac{\Gamma(H \to WW)}{\Gamma(H \to VV)} = d_{WW}\frac{c_W^2}{c_V^2}$$

$$D_{\tau\tau} = \frac{\sigma(gg \to H \to \tau\tau)}{\sigma(gg \to H \to VV)} = \frac{\Gamma(H \to \tau\tau)}{\Gamma(H \to VV)} = d_{\tau\tau}\frac{c_\tau^2}{c_V^2}$$

$$D_{\gamma\gamma} = \frac{\sigma(gg \to H \to \gamma\gamma)}{\sigma(gg \to H \to VV)} = \frac{\Gamma(H \to \gamma\gamma)}{\Gamma(H \to VV)} = d_{\gamma\gamma}\frac{c_\gamma^2}{c_V^2}$$

- $c_X = g_{HXX}/g_{HXX}^{SM}$, normalized coupling of the Higgs boson
- d_{XX} is the reduced decay ratio width, which only includes the gauge couplings and kinematical factors

Decay Ratios D_{XX}

Some Remarks

- the channels $H \to \mu^+\mu^-$ and $H \to \gamma Z$ can be also included at $\sqrt{s} \approx 14$TeV with high luminosity ($L \geq 100$ fb^{-1})
- c_γ is sensitive to contributions of new physics, due to the loop in the coupling
- c_W and c_Z can be used to test the custodial symmetry ($c_W = c_Z = c_V$) $\to$ if preserved, the WW and ZZ channels can be combined in the ratio normalization factor to increase statistics
- so far only $gg \to H$ was considered
- c_b^2/c_τ^2 would allow a test of the hierarchy of the Higgs-fermion couplings ($c_b^2/c_\tau^2 \approx 10$ in SM)

Decay Ratios D_{XX}

More Production channels

- in an experimental analysis one has to consider the fraction of all production channels, which are selected with efficiency ϵ^X

$$D_{XX} = \frac{\epsilon^X_{gg}\sigma(gg\to H)+\epsilon^X_{VBF}\sigma(qq\to Hqq)+\epsilon^X_{HV}\sigma(q\bar{q}\to VH)}{\epsilon^V_{gg}\sigma(gg\to H)+\epsilon^V_{VBF}\sigma(qq\to Hqq)+\epsilon^V_{HV}\sigma(q\bar{q}\to VH)} \times \frac{\Gamma(H\to XX)}{\Gamma(H\to VV)}$$

- the normalization has to be adopted to the specific analysis selection, to cancel out the main uncertainties
- E.g.: if one cuts on the zero jet channel, one would only select $gg \to H$ events
- can be easily expended to 1jet, 2jet, invisible ... channels

$$D^{(0j)}_{XX} = \frac{\sigma(gg\to H+0j\to XX)}{\sigma(gg\to H+0j\to VV)} = \frac{\Gamma(H\to XX)}{\Gamma(H\to VV)}$$

Cross Section Ratios C_{XX}

Definition

- to access some other important coupling of the Higgs boson, e.g. coupling to gluons or Higgs self-coupling, one has to consider different production cross sections in the ratio
- E.g.: coupling to gluons

$$C_{gg} = \frac{\sigma(gg \to H \to VV)}{\sigma(qq \to Hqq \to VVqq)} \propto \frac{c_g^2}{c_V^2}$$

- less uncertainties are cancel out compared to D_{XX}, but one can still remove uncertainties which are common among the different production channels (e.g. part of PDF uncertainties, lumi uncertainty, etc.)

Cross Section Ratios C_{XX}

Higgs self-coupling

- the Higgs self-coupling can be only determined using double Higgs production $gg \to HH$
- using the ration with single Higgs production allows a cancellation of QCD uncertainties
- but one needs knowledge about the branching fraction uncertainties
- high luminosity study

$$C_{HH} = \frac{\sigma(gg \to HH)}{\sigma(gg \to H)} \propto (ag_{HHH} + bg_{Htt})^2 \times \frac{\mathrm{BR}(H \to XX) \cdot \mathrm{BR}(H \to YY)}{\mathrm{BR}(H \to XX)}$$

Application on LHC Data

Analysis

- first (rough) calculation of the rations was performed using the published ATLAS anc CMS signal strength modifiers
- Assumptions:
  - i) effiencies for the selection of $H \to WW, ZZ, \gamma\gamma$ are the same
  - ii) uncertainties are dominated by statistical errors and systematical error, which are gaussian
  - iii) uncertainties are uncorrelated between different channels and ATLAS and CMS
  - iv) ATLAS and CMS results can be simply averaged

Application on LHC Data

Results

- Calculation decay ratios:

$$D_{WW} \equiv c_W^2/c_V^2 = 0.97 \pm 0.40$$
$$D_{ZZ} \equiv c_Z^2/c_V^2 = 1.04 \pm 0.46$$

$\rightarrow$ consistent with the custodial symmetry

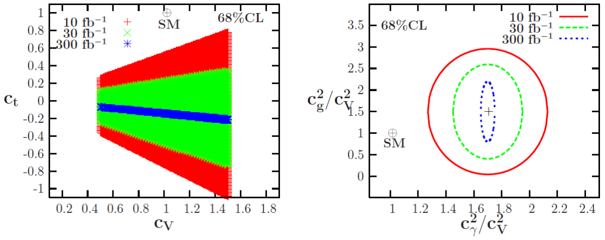
- the $D_\gamma\gamma$ is consistent with the SM prediction at the 95 % CL
- both could be checked with a accuracy of 25% by ATLAS and CMS until the end of the year

$$D_{\gamma\gamma} \equiv c_\gamma^2/c_V^2 = 1.70 \pm 0.43$$

Application on LHC Data

Extrapolation

- the 65% CL contours are shown for the c_t vs c_V plane and c_g^2/c_V^2 vs c_γ^2/c_V^2 plane
- extrapolation using the current results for $\sqrt{s} = 8$TeV with 10 and 30 fb^{-1} and for 300 fb^{-1} at $\sqrt{s} = 14$TeV
- assume that the central values stays the same as at the moment and the measurements will be limited only be statistics



Summary

Summary

- decay ratios D_{XX} were introduced, which allows the measurement of Higgs coupling to fermion and vector boson
- this observable is independent from all large number of uncertainties (experimental and theoretical) $\rightarrow$ measurements are not limited by theoretical uncertainties
- the cross section ratios C_{XX} are less powerful, but allow the measurement of additional couplings, like gluon- or Higgs self coupling
- some first calculations/extrapolations based on the current published LHC data were shown