Constraining new physics from Higgs measurements with Lilith: update to LHC Run 2 results

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Abstract

Lilith is public python library for constraining new physics from Higgs signal strength measurements. We here present an update of Lilith (version 1.2) including ATLAS and CMS Run 2 Higgs results for 36 fb^{-1}. Both the code and the XML database where extended from the ordinary Gaussian approximation employed in Lilith-1.1 to using variable Gaussian and Poisson distributions. We provide detailed validations of the implemented experimental results as well as a status of global fits for *i)* reduced Higgs couplings and *ii)* Two-Higgs-doublet models of Type-I and Type-II. We also comment on shortcomings in the presentation of the experimental results, which make their re-use difficult. Lilith-1.2 is available on GitHub and ready to be used to constrain a wide class of new physics scenarios.

1 Introduction

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2 Extended XML format

In the Lilith database, every single experimental result is stored in a different XML file. The original input formats from [1] are

- 1D intervals: best fit with 1σ errors;
- 2D likelihood contours: best fit, confidence level and parameters a, b, c which parametrize the inverse of the covariance matrix;
- full likelihood information as 1D or 2D grids of $-2\log L$.

For a detailed discussion and description of the XML format, we refer the reader to the original Lilith manual [1]. Here we just note that the first two options, 1D intervals and 2D likelihood contours, rely on an ordinary Gaussian approximation, which does not always describe the experimental data (i.e. the true likelihood) very well. Full 2D likelihood grids would be ideal but are rarely available.[1] We have therefore extended the XML format and fitting procedure in Lilith to include

- Gaussian distributions of variable width ("variable Gaussian") and
- generalized Poisson distributions.

The format follows the structure defined in [1] but setting `type="vn"` for a variable Gaussian and `type="p"` for a Poisson distribution in the <expmu> tag. Concretely:

1D variable Gaussian An example is the ATLAS result for $\mu(VH, ZZ)$ from HIGG-2016-22 which gives a 95% CL limit of $\mu < 3.7$. We assume that the best fit lies at zero, leading to a one-sided 1σ uncertainty of 1.85.

```
<expmu decay="ZZ" dim="1" type="vn">
  <experiment>ATLAS</experiment>
  <source type="published">HIGG-2016-22</source>
  <sqrts>13</sqrts>
  <mass>125.09</mass>

  <eff prod="VH">1.0</eff>

  <bestfit>0.</bestfit>

  <param>
  <uncertainty side="left">-0.0</uncertainty>
  <uncertainty side="right">1.85</uncertainty>
  </param>
</expmu>
```

The <bestfit> tag contains the best-fit value for the signal strength. The <uncertainty> tag contains the left (negative) and right (positive) 1σ errors. The computation of the likelihood in `computelikelihood.py` then follows Section 3.6 "Variable Gaussian (2)" of [3].

[1] We note that [2] strongly advocated the publication of full likelihood grids in 2 or more dimensions but unfortunately this wasn't followed up by the experimental collaborations.

2D variable Gaussian Taking the ATLAS result for $\mu(VBF, ZZ)$ and $\mu(ggH, ZZ)$ with correlation $\rho = -0.41$ from HIGG-2016-22 as an example:

```
<expmu decay="ZZ" dim="2" type="vn">
  <experiment>ATLAS</experiment>
  <source type="published">HIGG-2016-22</source>
  <sqrts>13</sqrts>
  <mass>125.09</mass>
  <CL>68\%</CL>  <!-- optional -->

  <eff axis="x" prod="VBF">1.0</eff>
  <eff axis="y" prod="ggH">1.0</eff>

  <bestfit>
    <x>4.0</x>
    <y>1.11</y>
  </bestfit>

  <param>
    <uncertainty axis="x" side="left">-1.46</uncertainty>
    <uncertainty axis="x" side="right">+1.75</uncertainty>
    <uncertainty axis="y" side="left">-0.21</uncertainty>
    <uncertainty axis="y" side="right">+0.23</uncertainty>
    <correlation>-0.41</correlation>
  </param>
</expmu>
```

Here, the `<bestfit>` tag specifies the location of the best-fit point in the `(x,y)` plane. The `<uncertainty>` tags contain the left (negative) and right (positive) 1σ errors for the `x` and `y` axes. The `<correlation>` tag specifies the correlation between `x` and `y`. The computation of the likelihood again follows Section 3.6 “Variable Gaussian (2)” of [3].

1D Poisson

```
<expmu decay="gammagamma" dim="1" type="p">
  <experiment>CMS</experiment>
  <source type="published">HIG-16-040</source>
  <sqrts>13</sqrts>
  <mass>125</mass>

  <eff prod="VH">1.</eff>

  <bestfit>2.4</bestfit>

  <param>
    <alpha>6.66515303803</alpha>
    <nu>48.9221714101</nu>
  </param>
</expmu>
```

The `<bestfit>` tag again contains the best-fit value for the signal strength, while the tags `<alpha>` and `<nu>` specify the scaling and skew of the function according to Section 3.4 “Generalised Poisson”, eq. (10a), of [3].

2D Poisson .... *TODO: add explanation* ....

3 ATLAS and CMS results included in the database update

3.1 ATLAS Run 2 results for 36 fb^{-1}

$H \to \gamma\gamma$: HIGG-2016-21

The ATLAS analysis [4] provides in Fig. 12 the 1D signal strengths measured for the different production processes: ggH, VBF, VH and "top" (ttH+tH). Moreover, the paper provides a variety of results for simplified template cross sections (STXS) including, in Fig. 40a, the observed correlations between the measured stage-0 STXS. Likelihood contours at 68% and 95% CL in the $\sigma(ggH) \times \mathrm{BR}(H \to \gamma\gamma)$ vs. $\sigma(VBF) \times \mathrm{BR}(H \to \gamma\gamma)$ plane are shown in Fig. 15 of [4]. Finally, auxiliary Figs. 23a–d show the 1D profile likelihoods of the signal strengths for ggH, VBF, VH and top production modes. As validation material, we have likelihood contours in the C_g vs. C_γ plane in Fig. 18a and in the C_V vs. C_F plane in Fig. 18b.[2] With no HepDATA record available for this analysis, all these figures had to be digitized "by hand".

It turns out that the ordinary Gaussian approximation, using the 1D signal strengths with their correlations or a bivariate Gaussian distribution fitted from the 68% CL contour of Fig. 15 (normalized to SM), does not describe the data well. In fact, the 1D profile likelihoods of the signal strengths have a Poisson shape. We therefore parametrize $\mu(ggH, \gamma\gamma)$ vs. $\mu(VBF, \gamma\gamma)$ as a 2D Poisson distribution with correlation -0.27, starting from the 1D profile likelihoods from auxiliary Figs. 23a,b of [4]. For $\mu(VH, \gamma\gamma)$ and $\mu(ttH, \gamma\gamma)$, we use 1D Poisson distributions fitted from auxiliary Figs. 23c,d. The impact on the C_V vs. C_F fits from using Gaussian or Poisson likelihoods is illustrated in Figure 1. Clearly, the Poissonian case reproduces much better the official ATLAS fits.

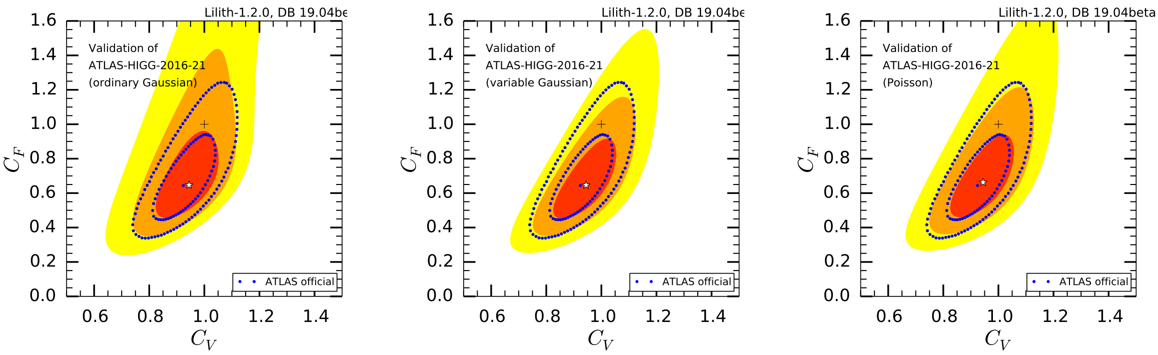

Figure 1: Fits of C_V vs. C_F using data from the ATLAS $H \to \gamma\gamma$ measurement [4]; the signal strength measurements are implemented, from left to right, as ordinary Gaussian, variable Gaussian and Poisson likelihoods.

[2]The reduced couplings κ_X in the experimental papers are denoted as C_X in Lilith.

$H \to ZZ^* \to 4l$: HIGG-2016-22

$H \to WW^* \to 2l2\nu$: HIGG-2016-07

$H \to \tau\tau$: HIGG-2017-07

$H \to b\bar{b}$: HIGG-2016-29 (VH) and HIGG-2016-30 (VBF)

ttH

$H \to inv$: HIGG-2016-28

Results from the search for invisibly decaying Higgs bosons produced in association with a Z boson are presented in [5]. Assuming the Standard Model ZH production cross-section, an observed (expected) upper limit of 67% (39%) at the 95% confidence level is set on BR($H \to inv$) for $m_H = 125$ GeV. We use $1 - \mathrm{CLs}$ as function BR($H \to inv$) extracted from auxiliary Figure 1c on the analysis' webpage.

3.2 CMS Run 2 results for 36 fb^{-1}

4 Status of Higgs coupling fits

5 Conclusion

must include a conclusion.

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A Overview of XML data files

B Implementation of 2D Poisson likelihood with correlation

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