Combining ATLAS and CMS results what have we learnt from the past

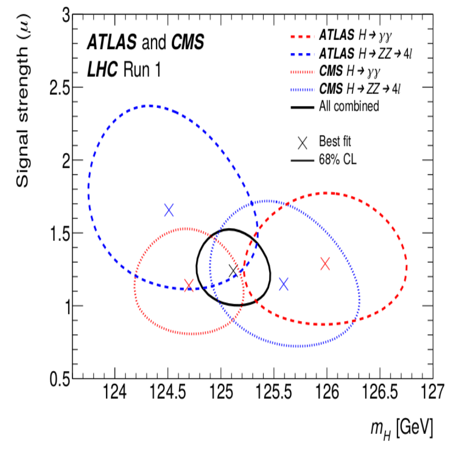
Pietro Vischia[1]

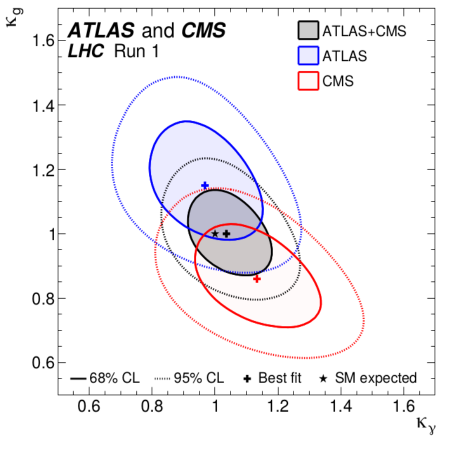
[1] Universidá d'Uviéu

Benasque — Higgs Toppings 2018

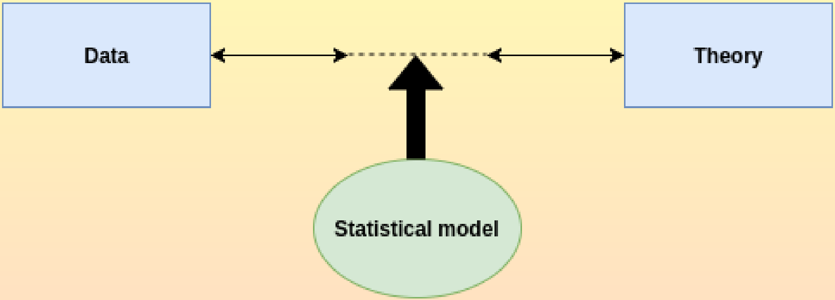
The Higgs case (sorry for the toppers!)

- Combining the Higgs boson mass: arXiv:1503.07589
- Combining the Higgs couplings: arXiv:1606.02266





The profile likelihood approach



- We model our problem using profile likelihoods (See Michele's talk)

$$\mathcal{L}(\boldsymbol{n}, \boldsymbol{\alpha}^{\mathbf{0}} | \mu, \boldsymbol{\alpha}) = \prod_{i \in bins} \mathcal{P}(n_i | \mu S_i(\boldsymbol{\alpha}) + B_i(\boldsymbol{\alpha})) \times \prod_{j \in syst} \mathcal{G}(\alpha_j^0 | \alpha_j, \delta\alpha_j)$$

$$\lambda(\mu) = \frac{\mathcal{L}(\mu, \hat{\hat{\boldsymbol{\alpha}}}_\mu)}{\mathcal{L}(\hat{\mu}, \hat{\boldsymbol{\alpha}})}$$

Defining parameters of interest

- Mass

$$\Lambda(m_H) = \frac{L\left(m_H\,,\ \hat{\hat{\mu}}^{\gamma\gamma}_{ggF+t\bar{t}H}(m_H)\,,\hat{\hat{\mu}}^{\gamma\gamma}_{VBF+VH}(m_H)\,,\ \hat{\hat{\mu}}^{4\ell}(m_H)\,,\ \hat{\hat{\boldsymbol{\theta}}}(m_H)\right)}{L(\hat{m}_H, \hat{\mu}^{\gamma\gamma}_{ggF+t\bar{t}H}\,, \hat{\mu}^{\gamma\gamma}_{VBF+VH}, \hat{\mu}^{4\ell}, \hat{\boldsymbol{\theta}})}\ .$$

  - One mass parameter
  - One signal strength per production mode (ggF+$\mathrm{t\bar{t}H}$, VBF+VH, 4ℓ)

- Couplings

$$\Lambda(\kappa_F, \kappa_V) = \frac{L(\kappa_F, \kappa_V, \hat{\hat{\vec{\theta}}}(\kappa_F, \kappa_V))}{L(\hat{\kappa}_F, \hat{\kappa}_V, \hat{\vec{\theta}})}\ .$$

  - Assume all fermion and weak vector boson couplings are described by only two parameters

Harmonize the inputs

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- Between the publication of individual results and the combination **time passes**
  - Updated theoretical cross sections (different central values, smaller uncertainties)
  - Updated theoretical modelling (e.g. resummed p_T spectrum for gluon-gluon fusion)
- The longer we wait, the more the updates needed
  - We end up combining not really the published individual measurements
  - Combination paper individual results may differ from the original individual results

- ATLAS now uses the Stewart-Tackmann prescription [48] for the jet bin uncertainties in the $H \to WW$ channel instead of the jet-veto-efficiency procedure [49];
- CMS now includes the bbH, tH, and $ggZH$ production processes in the signal model for all the channels in which they are relevant;
- CMS now uses the signal cross section calculations from Ref. [32] for all channels;
- CMS now adopts a unified prescription for the treatment of the Higgs boson p_{T} in the ggF production process, as described in Section 2.2;
- The cross sections for the dominant backgrounds were adjusted to the most recent theoretical calculations in the cases where they are estimated from simulation (ZZ background in the $H \to ZZ$ channel and ttZ and ttW backgrounds in the ttH channels);
- Both experiments have adopted the same correlation scheme for some of the signal theoretical uncertainties: for example, the treatment of the PDF uncertainties in the signal production cross sections now follows a common scheme for all decay channels, as described in Section 3.3.

The total effect of these modifications is small, both for the expected and observed results. All measurements differ from the individual combined results by less than approximately 10% of the total uncertainty for CMS and by even less for ATLAS.

Correlating uncertainties

- Experimental effects mostly uncorrelated (different detectors)
  - Caveat: neglecting some effects (e.g. assuming the same Z boson mass for calibrating the absolute energy)
  - Usually negligible
- Theoretical predictions mostly fully correlated (same underlying theory)
  - It is important to harmonize the treatment of each correlated systematic uncertainty
  - Caveat: clarify the meaning of *up* and *down*!!!
  - Caveat: use the same constraint p.d.f.s (usually gaussians, not trivial in case of two-point systematic)
- Luminosity measurements mostly partially correlated
  - Due to the imperfect knowledge of the beam currents

Correlation matrix depends on parameterization

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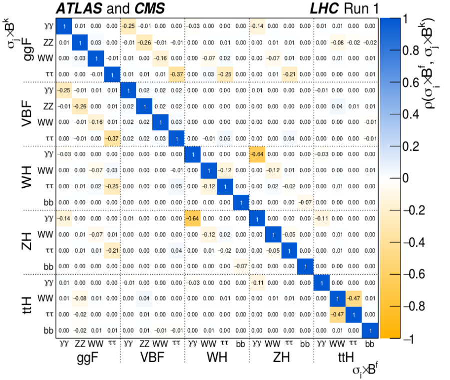

Figure 27: Correlation matrix obtained from the fit combining the ATLAS and CMS data using the generic parameterisation with 23 parameters described in Section 4.1.1. Only 20 parameters are shown because the other three, corresponding to the $H \to ZZ$ decay channel for the WH, ZH, and ttH production processes, are not measured with a meaningful precision.

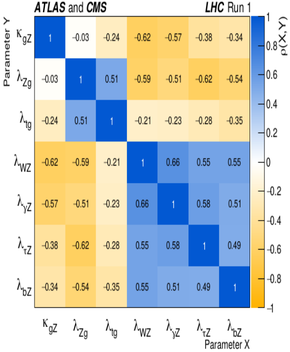

Figure 29: Correlation matrix obtained from the fit combining the ATLAS and CMS data using the generic parameterisation with seven parameters described in Section 4.2.

Presentation of the results

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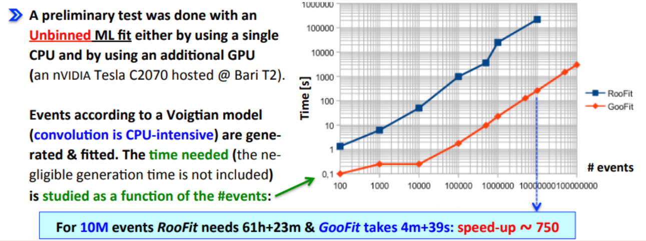
- See George's talk
- In general, so far provided only best-fists from Maximum Likelihood Estimate, uncertainties, and correlation matrices
- The smaller amount of published material, the larger the hit in the approximation for anyone using these results (theoreticians...)

Unfolding

- In general, the most important thing you must know about unfolding is that it is generally a bad idea to do it
  - Inverse problems not always well defined, regularization bias must be studied, best practices to be followed
- Nevertheless, useful for theoreticians, so at some point we will combine fiducial differential measurements
  - But be careful: in some cases (e.g. unfolding result of a fit) interpretation in unfolded space is conditional to p.d.f. of other variables)
- What to use?
  - Discussions are ongoing on the methods
    - Likelihood approach? Other methods? A review: arXiv:1607.06910

The computational toll

- Many measurements based on the asymptotic approach
- For many cross-checks and sometimes for the main result we may want to use toys
  - Complexity of the model directly influences the amount of toys needed
- Can we take 1 week just to perform a single fit?
- Are GPU the solution?



Graphics from Cristella's talk at QCHS XII, https://indico.cern.ch/event/353906/contributions/2219983/

Summary

- Define the models (POIs)
- Harmonize the inputs and don't wait too much for combining
- Careful in definiting uncertainties, and in correlating them
- Towards unfolding combined differential measurements
- The computational toll

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THANKS FOR THE ATTENTION!