Public Likelihoods for Higgs Searches and Measurements

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Higgs Measurements

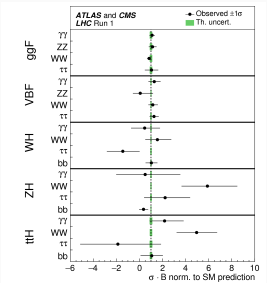
Results of a Higgs measurement:

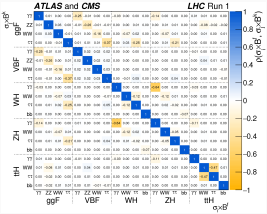
- \+ binned rate measurements
- \+ gaussian correlation matrix
- (+) mass, width [CMS 1901.00174], or CP-phase [CMS 2110.04836] measurements

$$\Rightarrow \chi^2 = (\mu - \hat{\mu})^T (\mathrm{Cov}_{\mathrm{exp}} + \mathrm{Cov}_{\mathrm{theo}})^{-1} (\mu - \hat{\mu})$$

Same for the (naive) combination of multiple analyses:

- theory uncertainty correlations
- experiment wide correlations (e.g. luminosity)





[ATLAS, CMS 1606.02266]

Higgs Measurements — Tools

Fit model predictions to the latest measurements of h_{125}. $\rightarrow \chi^2$ or Likelihood

Two public codes dedicated to this task:

HiggsSignals [Bechtle et al. 2012.09197]

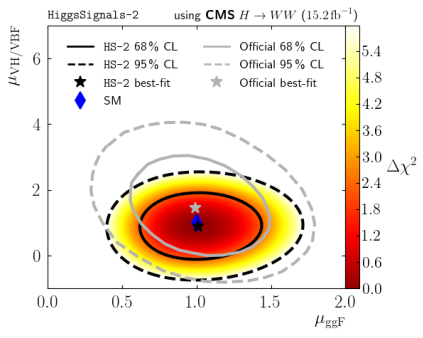
- stick to the gaussian limit with all available correlations (theory + experiment)
- STXS results to include differential effects
- \+ LHC Run 1 combination
- \+ Run 2 results $\leq 139\,\text{fb}^{-1}$

Lilith [Kraml et al. 1908.03952]

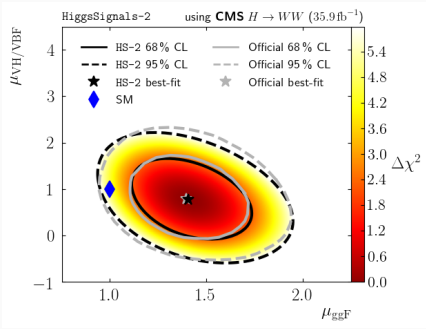
- stay inclusive but try to go beyond the gaussian limit
- use any available LLH information to better capture non-gaussian effects
- \+ LHC Run 1 combination
- \+ Run 2 results @$36\,\text{fb}^{-1}$

Higgs Measurements — Reconstructed LLH from μ Measurements

CMS $H \to WW$ signal-strength measurements in sub-channels aimed at different production modes.



no signal efficiencies [CMS HIG-16-021]



signal efficiencies [CMS 1806.05246]

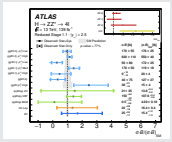
New 139 fb^{-1} analysis additionally includes inter-bin correlations but no usable validation plots! [CMS 2007.01984]

Higgs Measurements — Limitations of Reconstructed LLHs

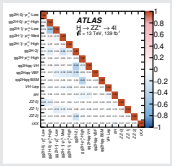
Example: ATLAS $H \to ZZ \to 4\ell$ [ATLAS 2004.03447]

HiggsSignals implementation

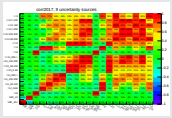
- measurements (12-bin STXS)



- experimental correlations

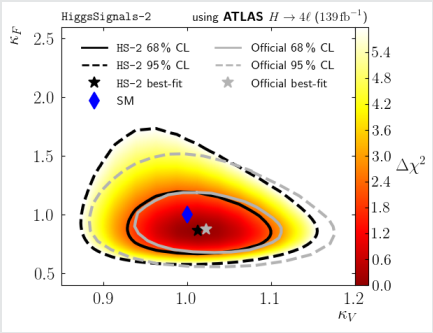


- theory correlations [2017 Scheme]



Performance of HiggsSignals

compared to official κ-fit.



Higgs Measurements — Open Likelihoods

Final goal: one combined LLH that covers everything

- all production$\times$decay modes, ideally in STXS bins
- mass and width measurements, CP-phases, ...

Immediate goal: open likelihoods for new analyses

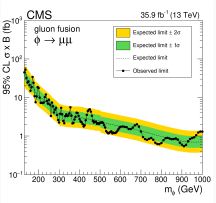
- publish a full LLH that can be simplified as needed
- a simplified $-2\ln\mathcal{L}$(binned rates) is directly applicable to pheno studies

Open questions

- who performs the simplification?
- multiple contributing particles (please don't use BR ratios!)

Higgs Searches

Most searches for additional scalars (and most resonance searches in general) present results as “model-independent” upper limits on some σ.



[CMS 1907.03152]

Assumption: BSM physics only scales the signal rate and Γ_{tot}.

- changing signal composition (e.g. $gg/bb \rightarrow H$)?
- interference effects?
- shape changes from BSM in loops?
- multiple particles of indistinguishable mass?

Higgs Searches — Tools

HiggsBounds

[Bechtle et al. 2006.06007]

- exclusion bounds from over 200 analyses at LEP, Tevatron and the LHC
- determine most sensitive analyses to obtain a combined limit at $\sim 95\,\%$ C.L..
- use model-independent limits (if possible) or check analysis assumptions

What if the signal composition can change?

worst: limit without additional information and SM-like assumptions

- have to assume SM-like signal composition

$\Rightarrow$ only usable with a *model-likeness test*: for each channel $\mu_{\text{channel}} \approx \mu$

better: provide SM-like signal efficiencies for each channel

- efficiencies stay unchanged as long as the other basic assumptions hold

best: LLH in the sub-channel rates

Higgs Searches — Simplified Likelihoods in $H \to \tau\tau$

Simplified exclusion likelihood profiles are available for:

- LEP Higgs Combination [ALEPH, DELPHI, L3, OPAL `hep-ex/0602042`]
- ATLAS and CMS $H \to \tau\tau$ searches [CMS `HIG-14-029`; ATLAS `1709.07242`; CMS `1803.06553`; ATLAS `2002.12223`]

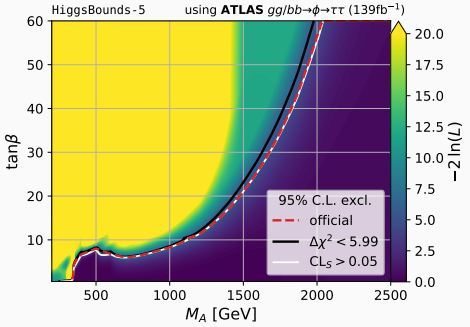
Likelihood profile as function of kinematical parameters and sub-channel rates.

$-2 \ln \mathcal{L}(m_h, \sigma(ggF \to \tau\tau), \sigma(bbH \to \tau\tau))$

$\to$ construct 95 % C.L. CL_S limits

$\to$ as likelihood contribution in a fit

Contains full information for all sub-channel rates.



Higgs Searches — Open Likelihoods

For model fits

- model fits currently have to incorporate Higgs searches as hard cuts
- available LLHs allow including the searches in the fit instead

To avoid model assumptions

- a LLH as a function of the sub-channel-rates avoids model assumptions
  - $\mathcal{L}(m_h, \sigma(pp \to \tau\tau))$ vs $\mathcal{L}(m_h, \sigma(ggF \to \tau\tau), \sigma(bbH \to \tau\tau))$
  - $pp \to H \to ZZ \quad \Rightarrow \quad [ggH + bbH + vbfH] \to ZZ$
  - $pp \to 4t \quad \Rightarrow \quad [ttH + (qq \to tH) + (gg \to tH) + tWH + ggF] \to tt$
- this may require extra work on the experimental side

For recasting

- see later talks

Summary

Higgs Measurements

- Gaussian limit results insufficient to reproduce highest precision channels
  - $\Rightarrow$ urgent need for LLH information
- better combination between different analyses
- incorporate mass, width and CP-measurements

Higgs searches

- (observed + expected) LLH $\geq$ cxn limit
  - immediately useful for model fits
  - allows reconstruction of the CL_s limits
  - allows recasting to modified kinematics
- LLH in the sub-channels to avoid model assumptions