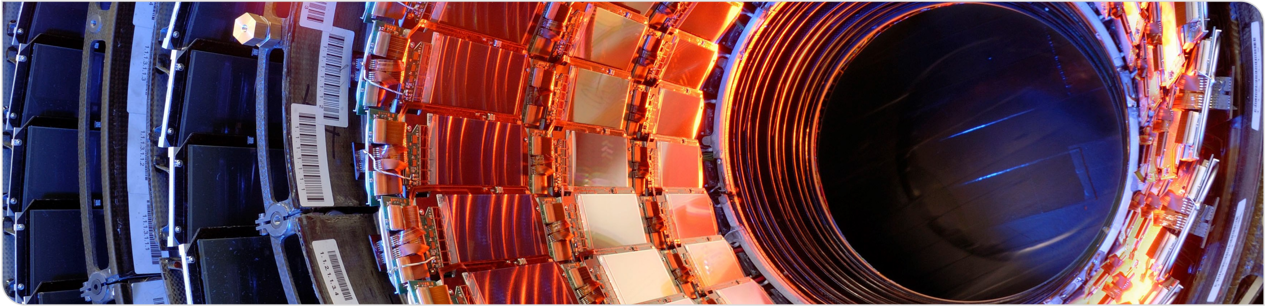
Karlsruhe Institute of Technology

Institute of Experimental Particle Physics

MSSM Predictions for SM-like Higgs Boson

Removing Mass-Dependence of Cross-Sections and Branching Fractions

Artur Gottmann on behalf of CMS BSM H $\rightarrow \tau\tau$ analysts | June 29, 2021



Introduction

- Current CMS BSM $H \rightarrow \tau\tau$ analysis: increased sensitivity to SM-like Higgs boson for model-dependent interpretations
- Major production channels: gluon fusion (**ggh**) and $(\mathrm{VBF} + \mathrm{V} \rightarrow \mathrm{qq})\mathrm{h}$ = **qqh**
- Encounter sensitivity to mass dependence of **production cross-sections** (σ) and **branching fractions** $(\mathrm{BR}(\mathrm{h} \rightarrow \tau\tau))$
- Agreed upon a rescaling procedure to remove this mass dependence by reweighting to a BSM prediction at the mass of the observed Higgs boson at 125.38 GeV

General idea illustrated for M_h^{125}

- Assume a factorization of mass dependence of and BSM contributions to predictions:

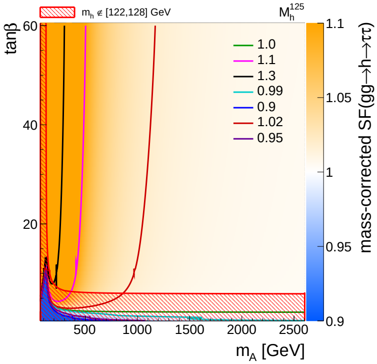
$$\sigma_{ggh}^{BSM}(125.38\text{ GeV}) = \sigma_{ggh}^{BSM}(m_h) \cdot \sigma_{ggh}^{SM}(125.38\text{ GeV})/\sigma_{ggh}^{SM}(m_h)$$
$$\sigma_{bbh}^{BSM}(125.38\text{ GeV}) = \sigma_{bbh}^{BSM}(m_h) \cdot \sigma_{bbh}^{SM}(125.38\text{ GeV})/\sigma_{bbh}^{SM}(m_h)$$
$$BR(h_{125.38\text{ GeV}}^{BSM} \to \tau\tau) = BR(h_{m_h}^{BSM} \to \tau\tau) \cdot BR(h_{125.38\text{ GeV}}^{SM} \to \tau\tau)/BR(h_{m_h}^{SM} \to \tau\tau)$$

- If considered processes scaled to SM prediction at 125.38 GeV, BSM scale factors are then:

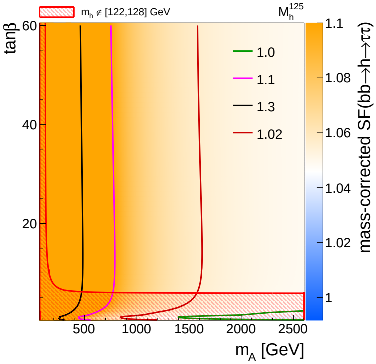
$$\mu_{ggh}^{BSM} = \sigma_{ggh}^{BSM}(m_h)/\sigma_{ggh}^{SM}(m_h) \cdot BR(h_{m_h}^{BSM} \to \tau\tau)/BR(h_{m_h}^{SM} \to \tau\tau)$$
$$\mu_{bbh}^{BSM} = \sigma_{bbh}^{BSM}(m_h)/\sigma_{bbh}^{SM}(m_h) \cdot BR(h_{m_h}^{BSM} \to \tau\tau)/BR(h_{m_h}^{SM} \to \tau\tau)$$
$$\mu_{qqh}^{BSM} = \sin^2(\beta - \alpha) \cdot BR(h_{m_h}^{BSM} \to \tau\tau)/BR(h_{m_h}^{SM} \to \tau\tau)$$

- Reweighting possible with `*_SM` histograms provided in ROOT files of benchmark models
- $\sin^2(\beta - \alpha)$ is scale factor for coupling to gauge bosons → no mass-dependence

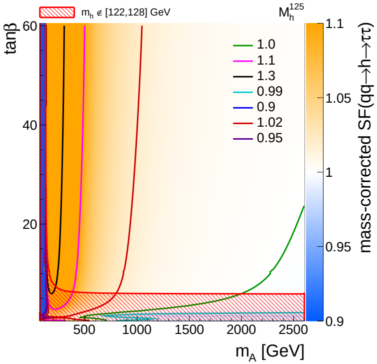
Scale factors obtained for M_h^{125}



μ_{ggh}^{BSM}



μ_{bbh}^{BSM}



μ_{qqh}^{BSM}

- Consider reweighting procedure as accurate for $m_h \in [122.38, 128.38]$ GeV

Relation to statistical inference

- The obtained scale factors $\mu_{\text{process}}^{\text{BSM}}$ can now be used in (slightly) different ways in statistical inference:
  - Comparing with signal strength measurements $\hat{\mu}_{\text{process}}$, as discussed e.g. in section 3.3.2 of arXiv:1808.07542
  - Make use of them in hypothesis tests, e.g. SM hypothesis (reference) against MSSM hypothesis (alternative)
- All these procedures make use of the likelihood $\mathcal{L}$ constructed in an analysis

$$\mathcal{L}(n|\mu \cdot s(\theta) + b(\theta))$$

  - n representing the data,
  - μ the signal strength parameter for the signal s,
  - b the background,
  - and θ all nuisance parameters.

Comparison with signal strengh measurements

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- A measurement of signal strength μ corresponds to the maximization of the likelihood $\mathcal{L}$ with respect to all parameters:

$$\mathcal{L}(n|\hat{\mu} \cdot s(\hat{\theta}) + b(\hat{\theta}))$$

- Thereby, $\hat{\mu}$ is the global maximum of $\mathcal{L}$:

$$\hat{\mu} = (\sigma \cdot \text{BR})_{\text{Best-fit}} / (\sigma \cdot \text{BR})_{\text{SM}}$$

- A (95%) confidence interval can then be obtained, by a (profiled) likelihood scan of μ around the measured value $\hat{\mu}$
- In case of a comparison with the measurement, it is then checked, whether μ^{BSM} is within the obtained confidence interval
  $\rightarrow$ This comparison also corresponds to upper limits obtained from **profiled** likelihood ratios:

$$\lambda = \frac{\mathcal{L}(n|\mu^{\text{BSM}} \cdot s(\hat{\theta}_{\mu^{\text{BSM}}}) + b(\hat{\theta}_{\mu^{\text{BSM}}}))}{\mathcal{L}(n|\hat{\mu} \cdot s(\hat{\theta}) + b(\hat{\theta}))}$$

MSSM vs SM hypothesis test

- Consider a likelihood ratio λ in case of such a hypothesis test:

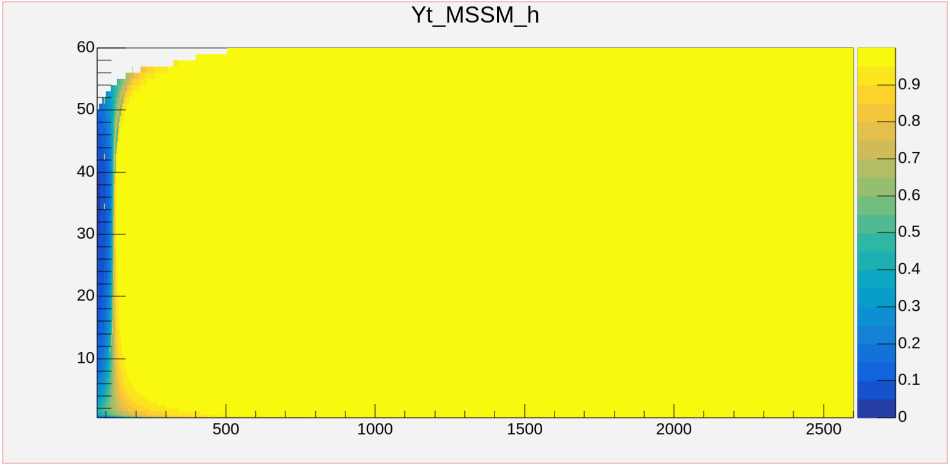
$$\lambda = \frac{\mathcal{L}(n|\mu^{BSM} \cdot s(\hat{\theta}_{\mu^{BSM}}) + b(\hat{\theta}_{\mu^{BSM}}))}{\mathcal{L}(n|\mu^{SM} \cdot s(\hat{\theta}_{\mu^{SM}}) + b(\hat{\theta}_{\mu^{SM}}))}$$

- For the numerator, parameters θ are optimized with respect to a **fixed** signal strength μ^{BSM}
- For the denominator, parameters θ are optimized with respect to a **fixed** signal strength μ^{SM}
- Obtain p-value from evaluating the cumulative distribution of λ under the alternative and reference hypothesiso
- Roughly speaking, we compare here μ^{BSM} with $\mu^{SM} = 1$.

Availability of inputs for rescaling

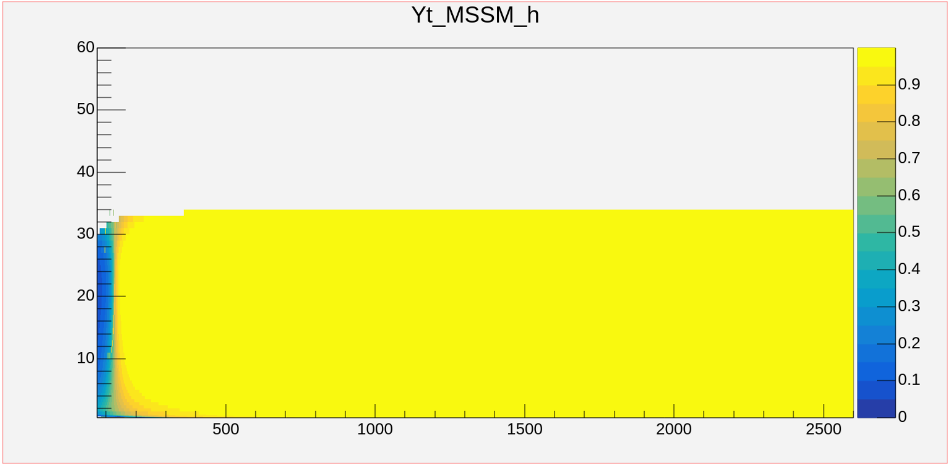
- Models with accurate inputs, in particular `*_SM` histograms:
  M_h^{125}, $M_h^{125}(\tilde{\tau})$, $M_h^{125}(\tilde{\chi})$, M_h^{125}(alignment)
- For $M_{h_1}^{125}$(CPV), `xs_gg_H1_SM` is always 0
- For M_H^{125}(alignment), `br_H_{tautau,...}_SM` and `width_H_SM` are missing
- For $M_{h,EFT}^{125}$ and $M_{h,EFT}^{125}(\tilde{\chi})$, `br_h_{tautau,...}_SM` and `width_h_SM` are missing
- For $M_h^{125}(\mu = -1\ \text{TeV})$, $M_h^{125}(\mu = -2\ \text{TeV})$ and $M_h^{125}(\mu = -3\ \text{TeV})$,
  all inputs are sometimes 0 or set to some fixed value. → See next slides for an example

$M_h^{125}(\mu = -1 \text{ TeV})$



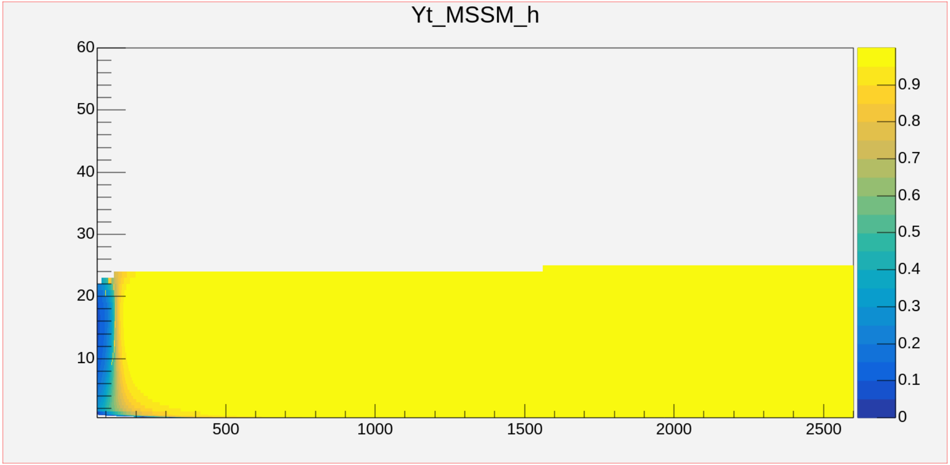
Considering only points up to $\tan\beta = 56$, excluding remaining invalid points from limit calculation

$M_h^{125}(\mu = -2\ \text{TeV})$



Considering only points up to $\tan\beta = 30$

$M_h^{125}(\mu = -3\ \text{TeV})$



Considering only points up to $\tan\beta = 20$

Summary

- Presented procedure we agreed upon to remove the mass dependence for the predictions of the SM-like Higgs boson from MSSM scenarios
  $\longrightarrow$ Leads to expected effects (also in the final exclusion results not shown here)
- Explained its relation to various methods in statistical inference
- Checked availability of inputs for this rescaling procedure $\longrightarrow$ Time-scale to expect corrected inputs for corresponding scenarios?
- Procedure not only relevant for BSM H $\rightarrow \tau\tau$ analysis, but also for interpretations of combined SM measurements
  $\longrightarrow$ If everyone agrees, I will create a recommendation to be put on the Twiki page (to be review e.g. via e-mail)
- Another point to be put on Twiki brought up by Tim Barklow (unrelated to SM-like predictions): A summary on parameters to be provided as (profiled) likelihoods scans by model-independent searches