Measurement of Differential Higgs Boson Cross Section with the Di-Tau Decay Channel at CMS

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On behalf of the CMS Collaboration

Introduction

Analysis	Link To Documentation	arXiv link
$H\tau\tau$ Differential Cross Section Analysis	CMS-PAS-HIG-20-015	2107.11486

- $H \rightarrow \tau\tau$ decays…
  - … provide direct observation of the yukawa coupling
  - … have a high branching fraction that allows for measurements of rarer parts of Higgs Phase space (high transverse momentum, large jet multiplicity, etc)
- The $H \rightarrow \tau\tau$ had its first observation in 2016, and is now the target of increasingly precise measurements
  - STXS measurements (Anne-Catherine's Talk) (Official Documentation)
  - Differential Measurements

Differential Analysis

- This analysis targets an inclusive and differential fiducial higgs XS measurement using $H \rightarrow \tau\tau$ decays
  - Provides a more model independent way to look at Higgs physics in secondary variables than the STXS scheme, but integrates over production modes
- Three variables are considered that provide the most interesting measurements and where the $H \rightarrow \tau\tau$ channel can contribute
  - Higgs Pt ← **Offers particularly good probe of BSM Physics**
  - Jet Multiplicity
  - Leading Jet Pt
- The $H \rightarrow \tau\tau$ channel offers a good way to examine low cross section regions of phase space
  - High branching fraction to massive taus
- This is the first time that a differential analysis has been performed for the $H \rightarrow \tau\tau$ channel at the LHC

Differential Analysis Strategy

- The Di-Tau decay is picked up in 4 channels: $\tau_h\tau_h, \mu\tau_h, e\tau_h, e\mu$
- Fiducial region defined similarly to offline selection
- In order to maintain independence from the three differential variables, the analysis is categorized based on tau pt
  - S/B increases with p_t^τ
  - $e\mu$ left uncategorized
- Three categories are used:
  - Low p_t^τ: 30-50 GeV (40-50 GeV for $\tau_h\tau_h$)
  - Intermediate p_t^τ: 50-70 GeV
  - High p_t^τ: 70+ GeV

Likelihood Fitting

- Results are extracted as a simultaneous fit maximizing the likelihood function of the form:

Signal Strength Modifier

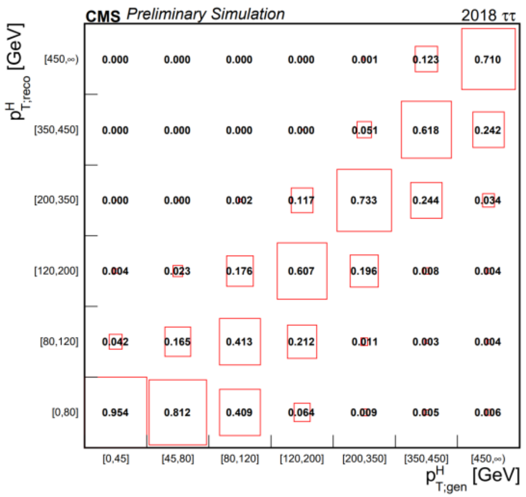
$$\mathcal{L} = \prod_i Poisson\left(n_i \sum_j \left[R_{ij}(\boldsymbol{\theta})\mu_j\right] + b_i\right) \cdot \mathcal{C}(\theta_i(\mu))$$

Observed Events

Response matrix:

Nuisance Constraints

Reconstructed Background



Regularization

- To remove unphysical (statistical) fluctuations of parameters, regularization is employed
- A penalty term of the form:

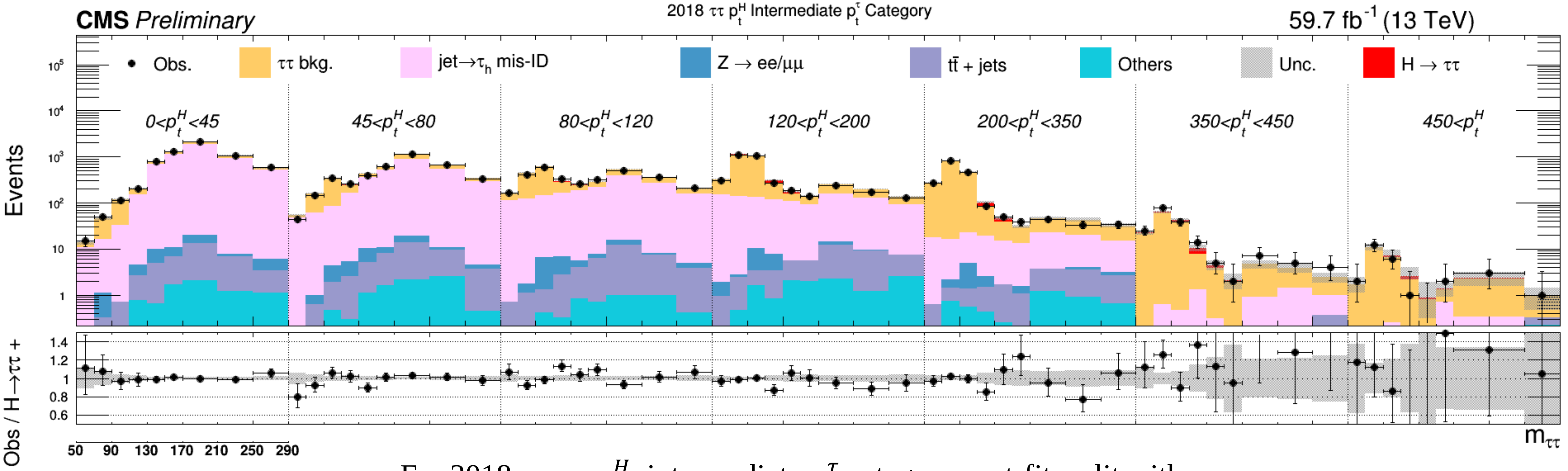
$$\mathcal{K}(\boldsymbol{\mu}) = \prod_{j=1}^{M-2} \exp\left(\frac{-\left[(\mu_{j+1} - \mu_j) - (\mu_j - \mu_{j-1})\right]^2}{2\delta^2}\right)$$

Where M is the number of bins, and δ controls the strength of the regularization is multiplied in the likelihood function

- δ is optimized to minimize mean global correlation coefficient

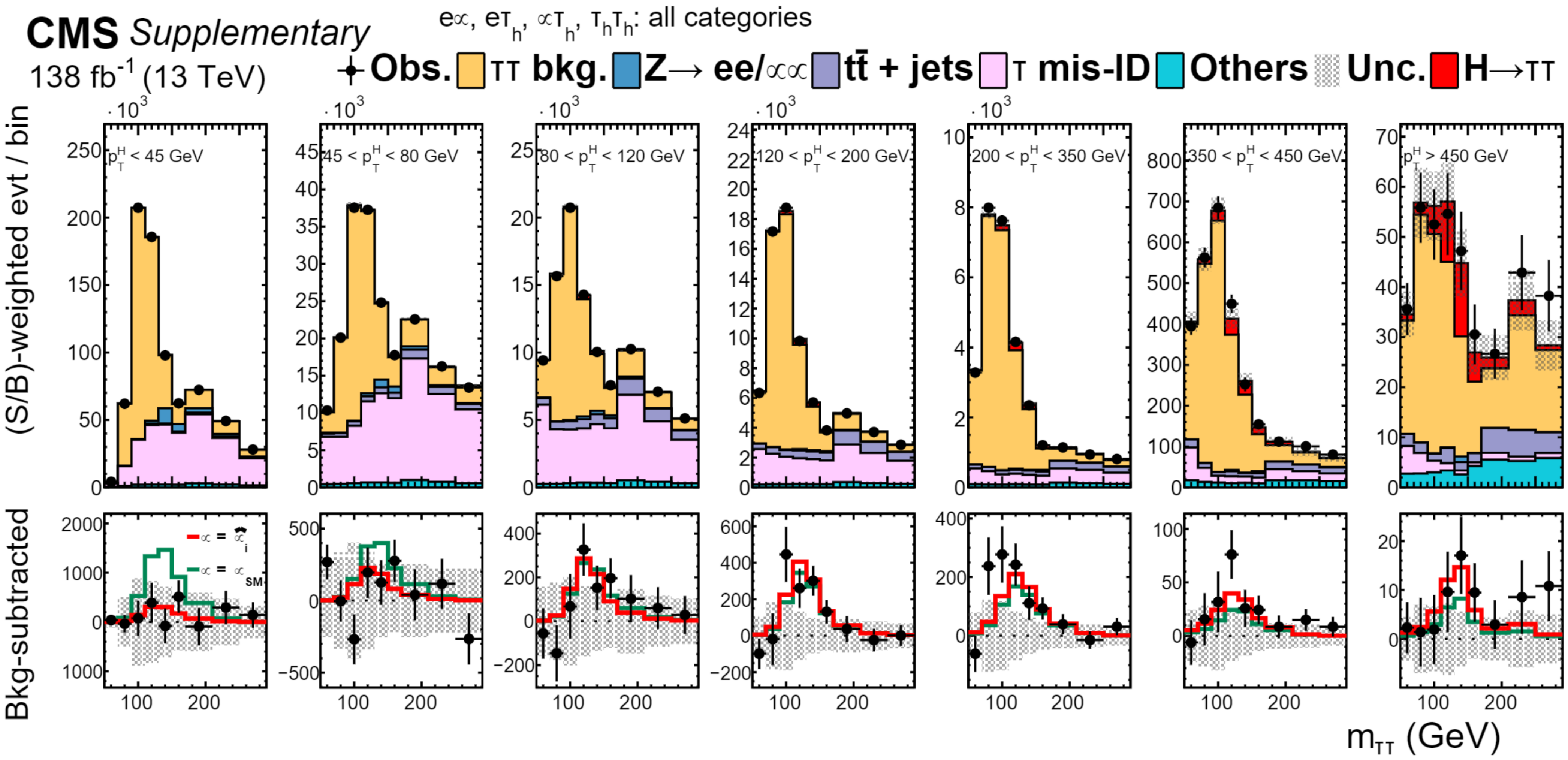
Categorization and Signal Extraction

- Categories use di-tau mass as a primary observable
  - Categories also split further with each observable parameter given a bin, except where statistics do not permit it

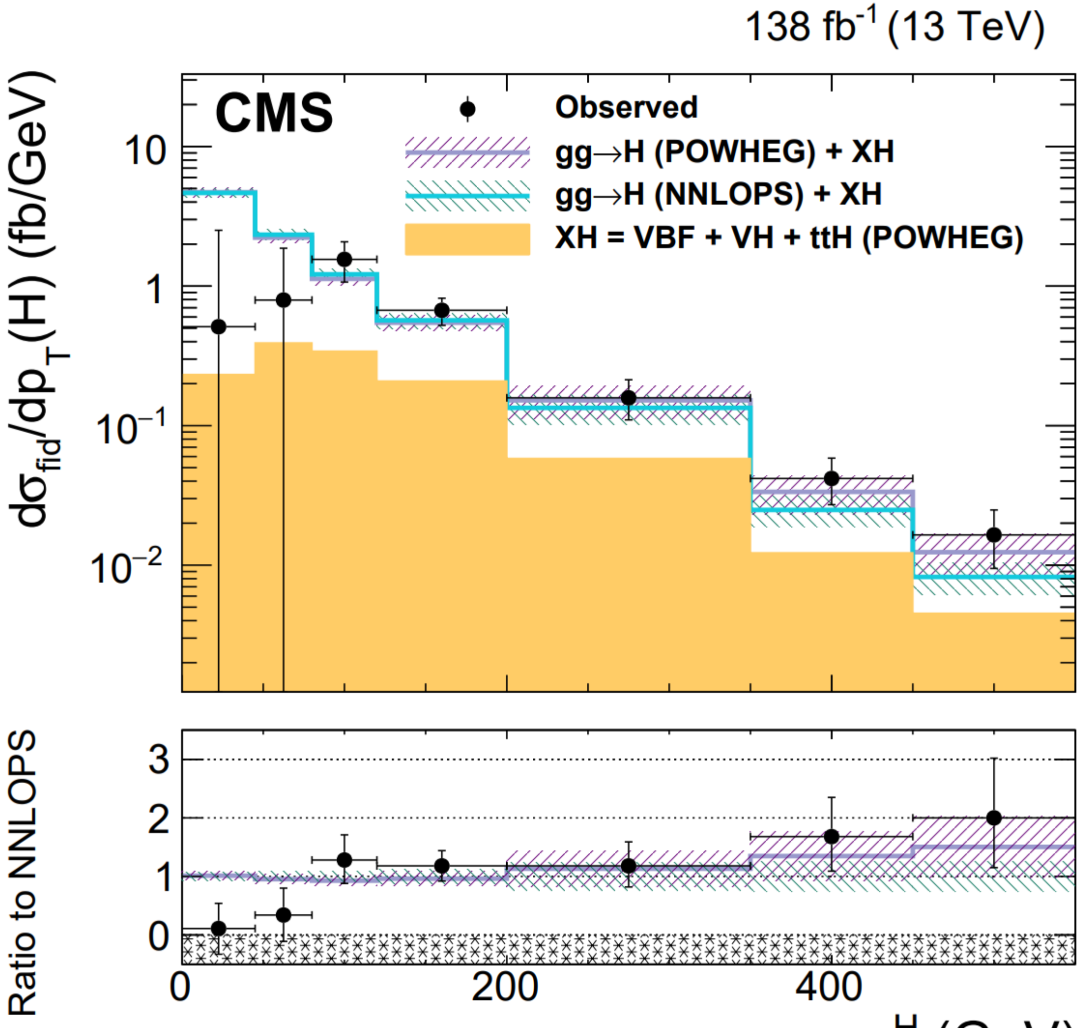


Ex. 2018 $\tau_h\tau_h$, p_t^H, intermediate p_t^τ category post-fit, split with one reconstruction p_t^H bin for each signal p_t^H bin

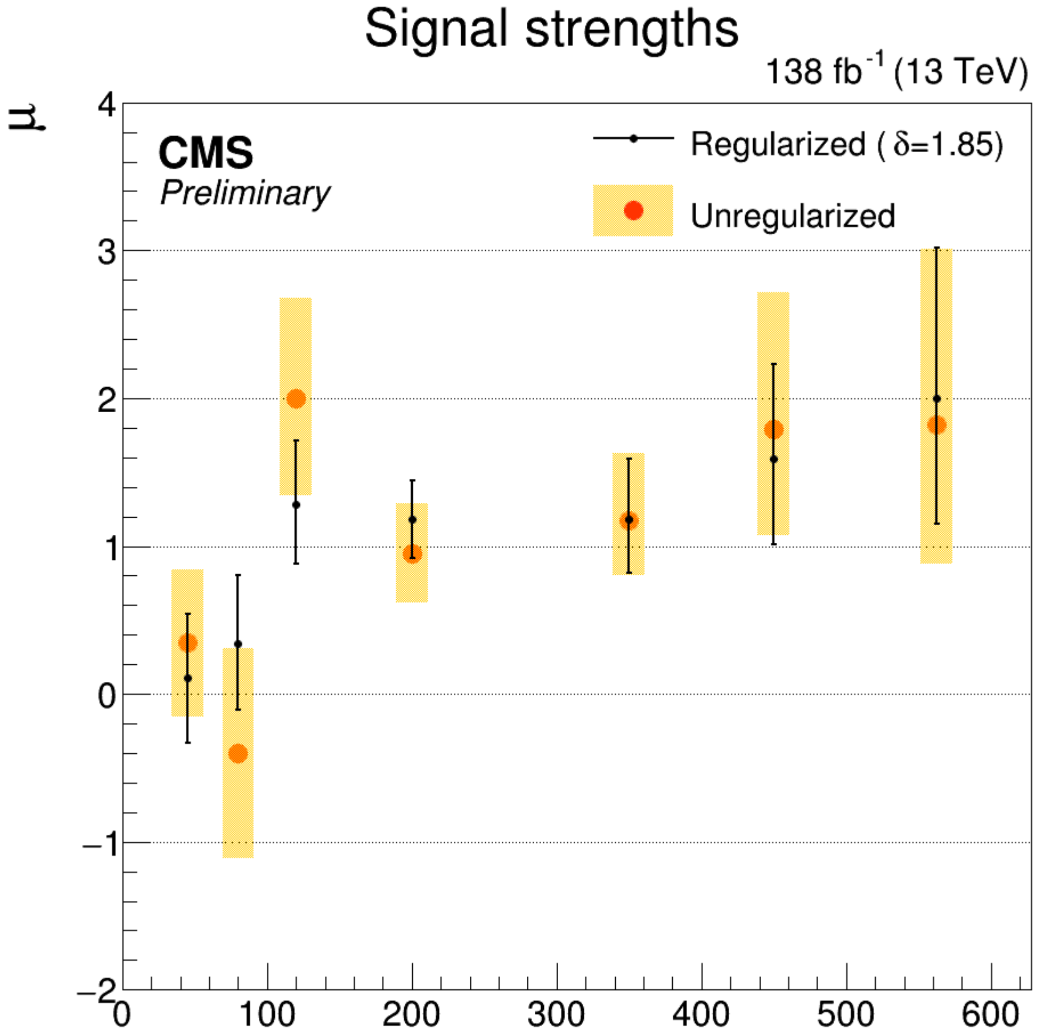
S/B Weighted Plots (p_t^H)



Differential X-Sec (p_t^H)

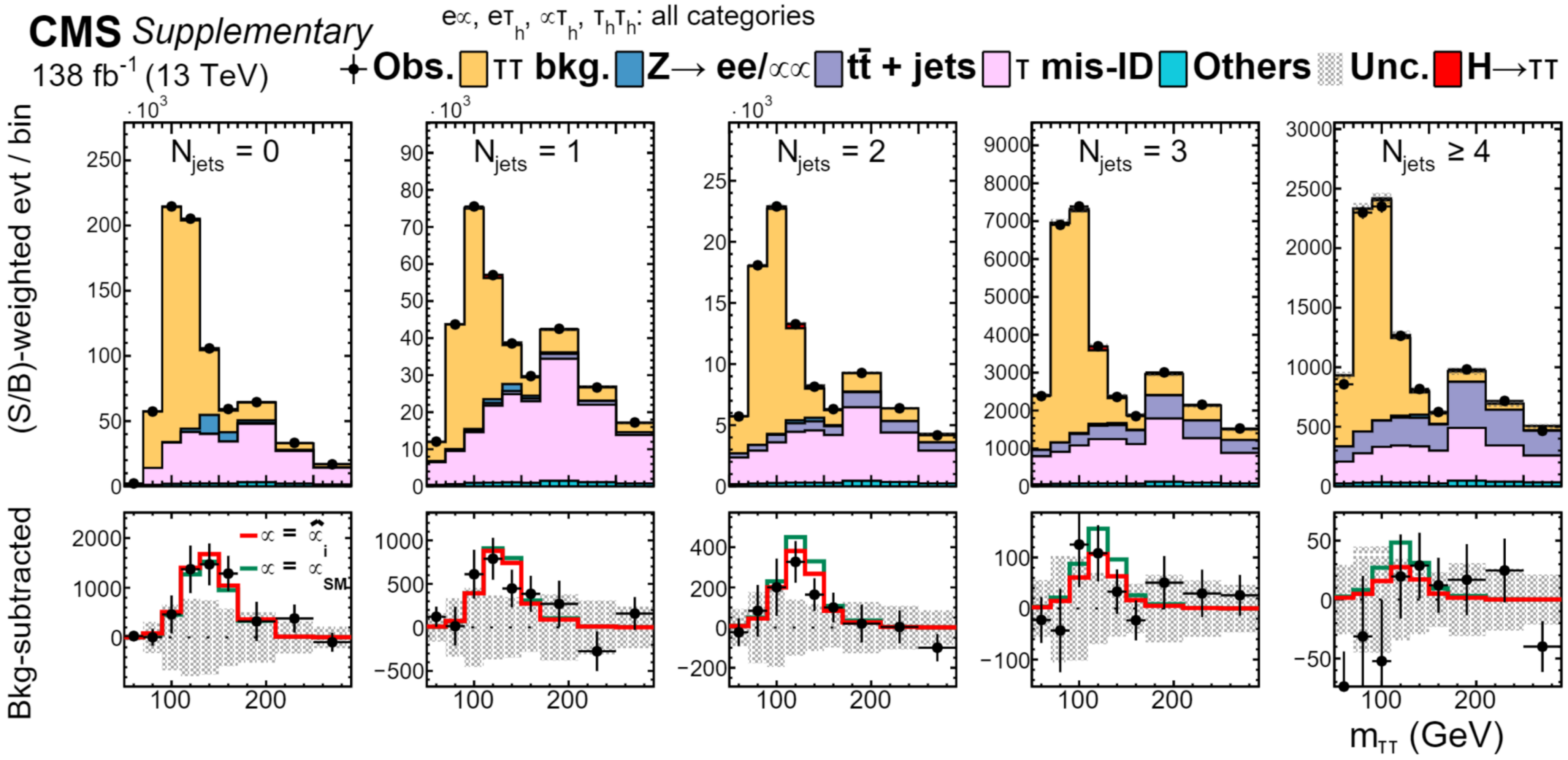


$\sigma_{fid}: 426 \pm 102\ fb$

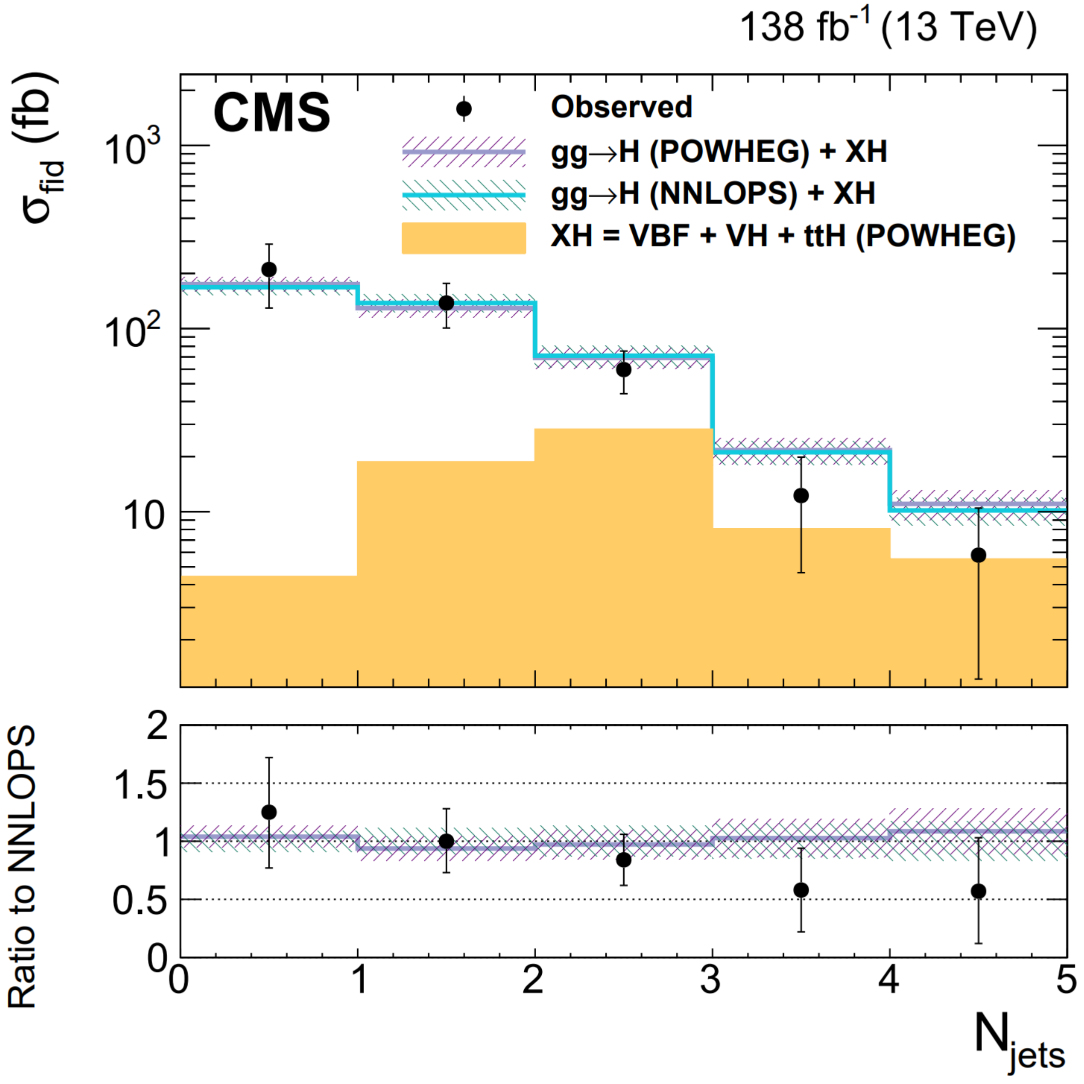


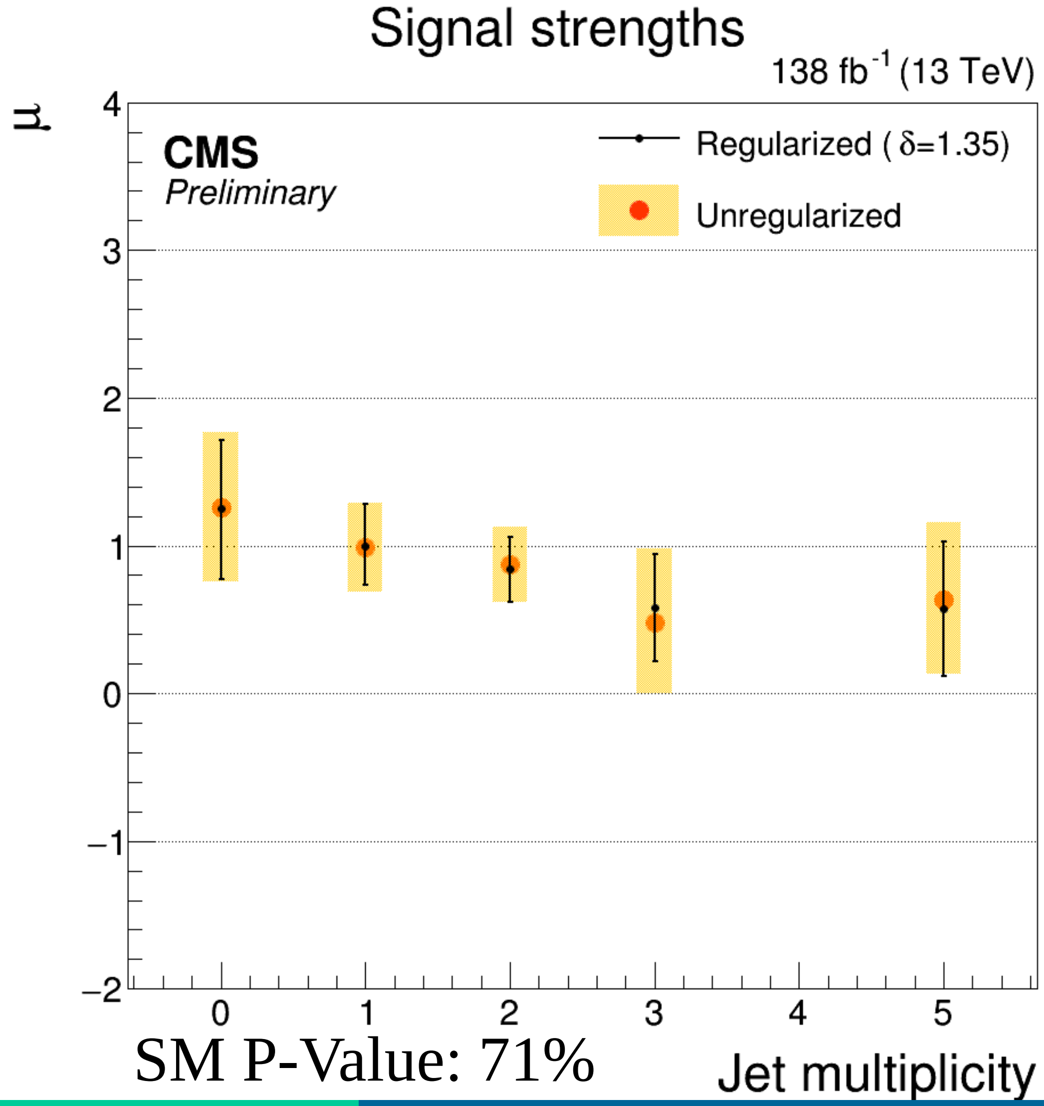
SM P-Value: 17%

S/B Weighted Plots (N_{jets})



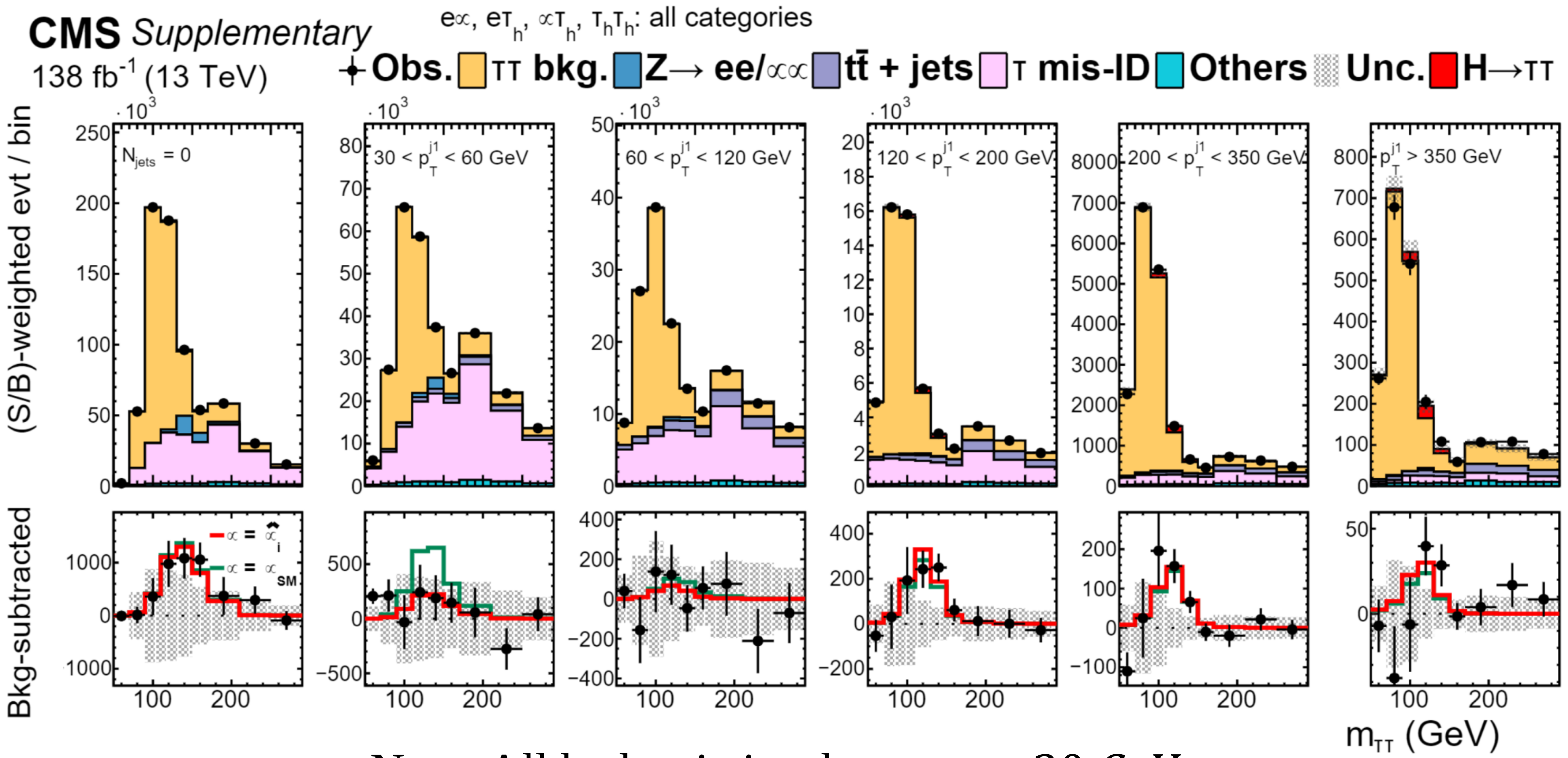
Differential X-Sec (N_{jets})





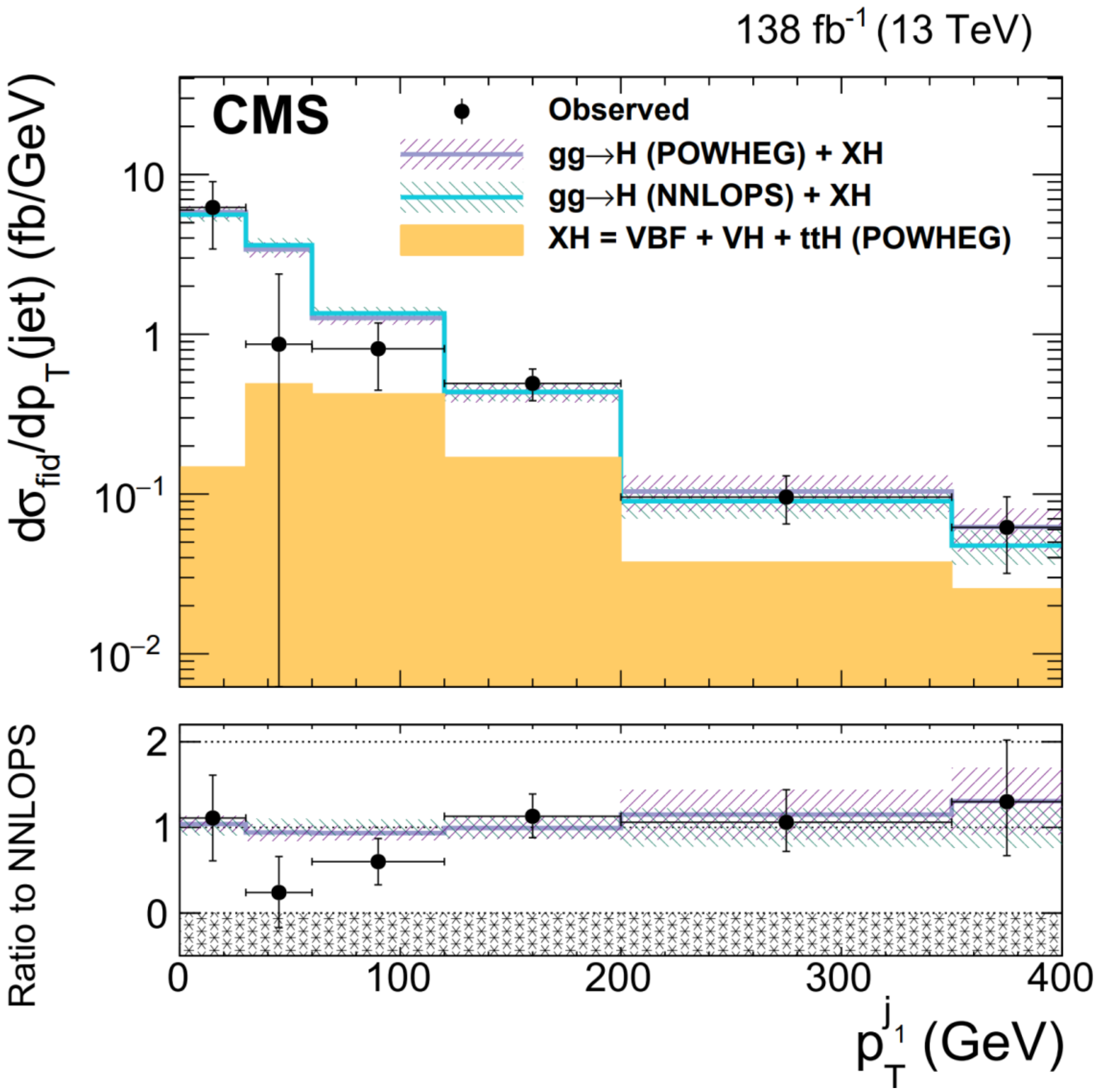
SM P-Value: 71%

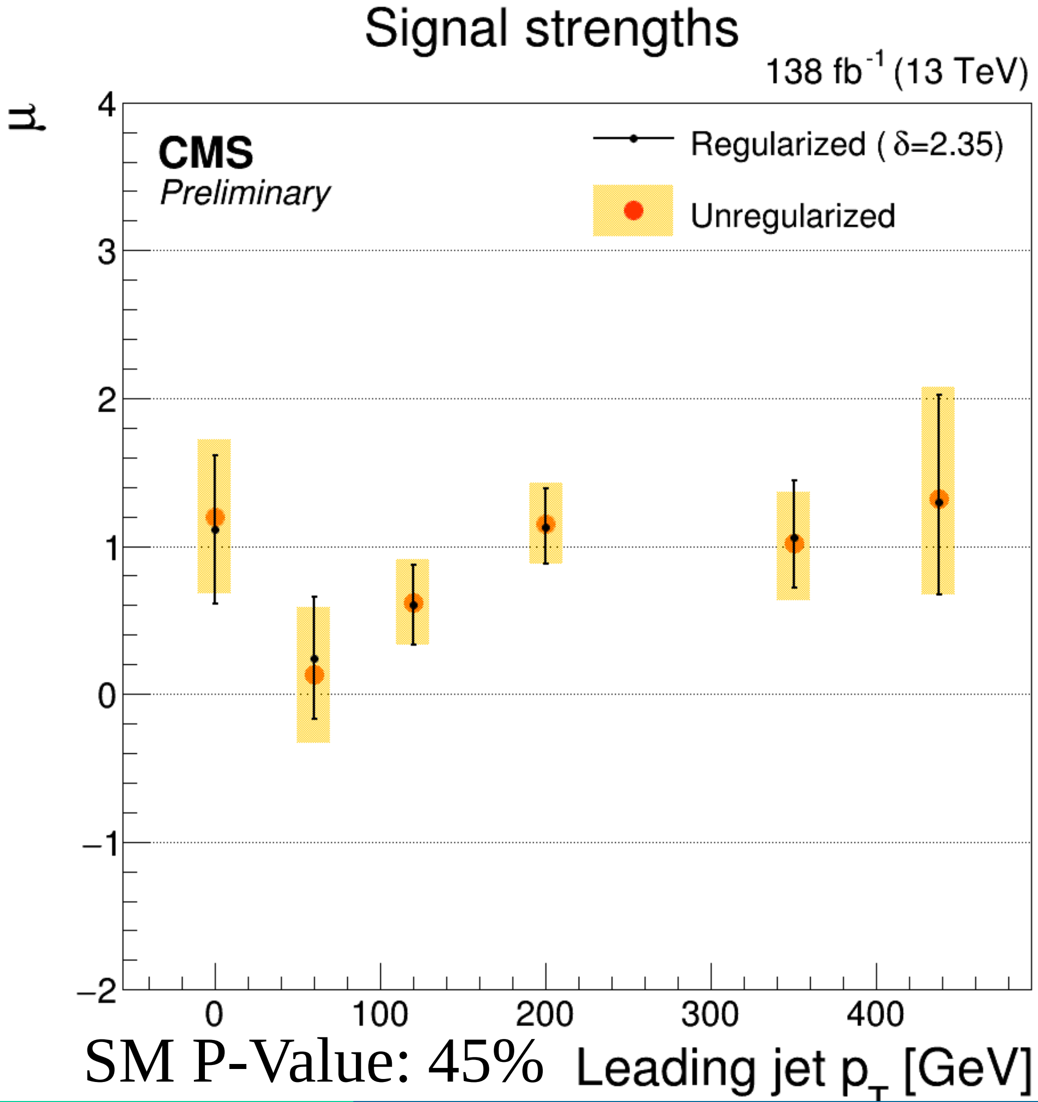
S/B Weighted Plots (Leading Jet p_t)



Note: All hadronic jets have $p_t > 30\ GeV$

Differential X-Sec (Leading Jet p_t)





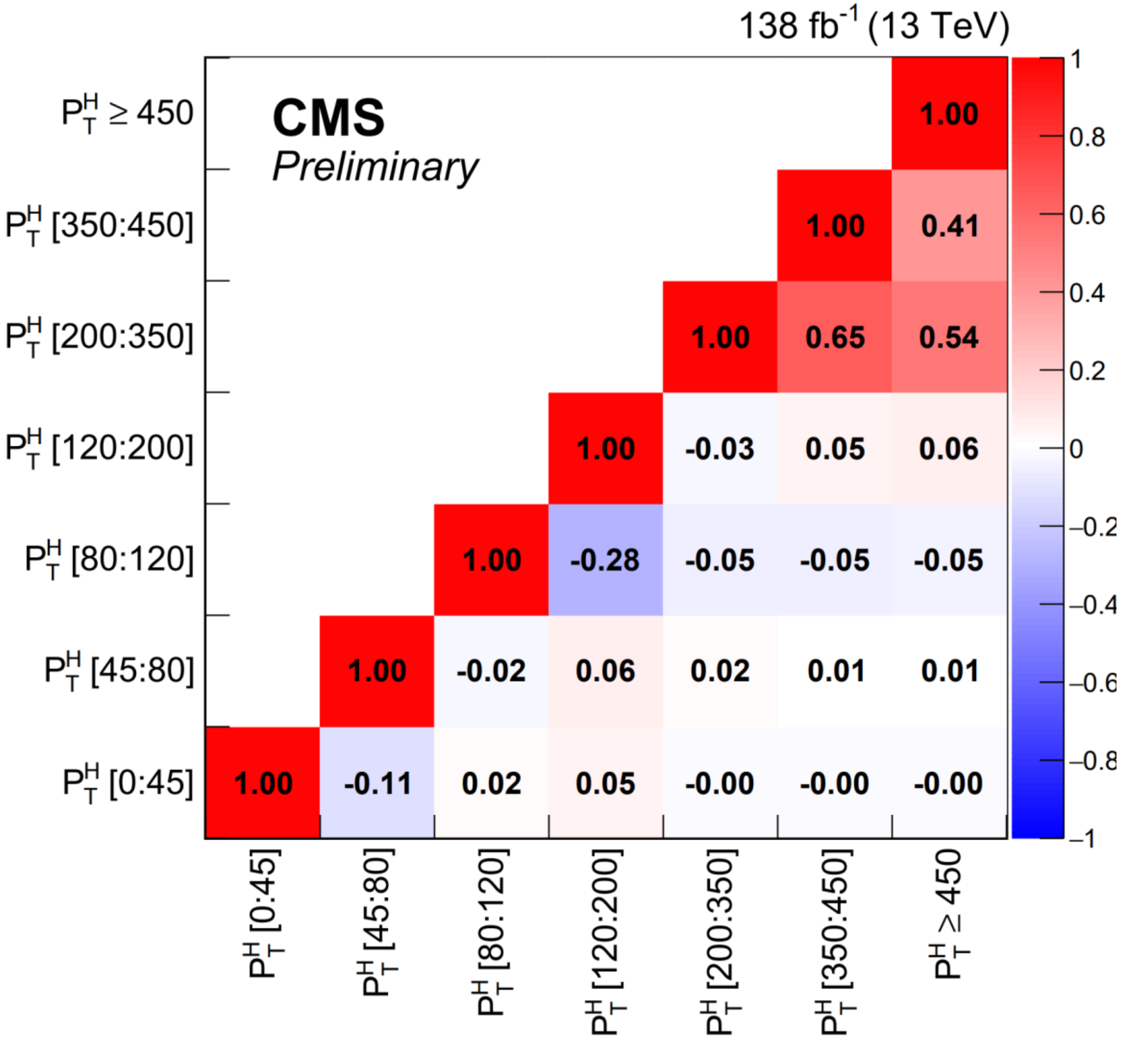
SM P-Value: 45%

Summary

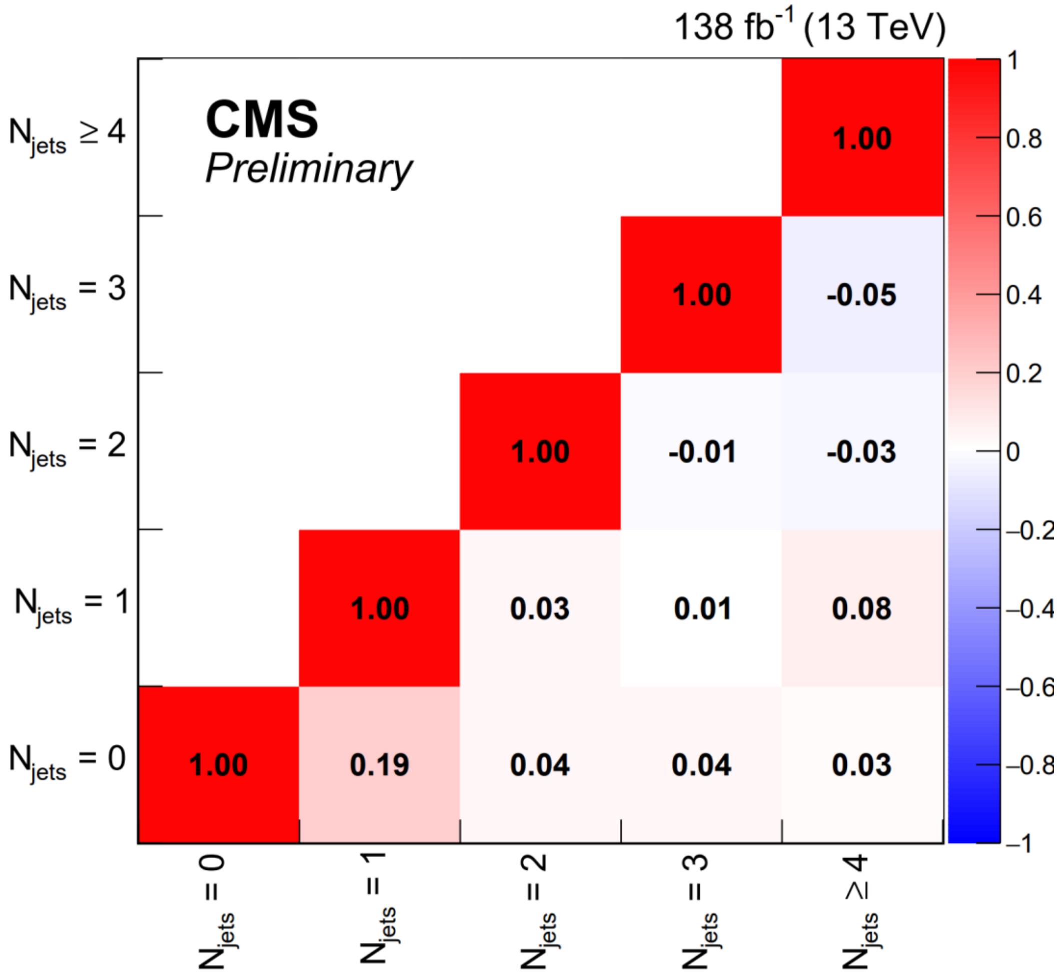
- This is the first time that a differential analysis has been performed for the $H \rightarrow \tau\tau$ channel
- The differential analysis shows good agreement with SM expectation
  - Values largely agree within uncertainties
  - P-values (with respect to SM)17%/71%/45% for p_t^H /N_{Jets}/Leading Jet p_t
- Particularly precise, with comparable precision in the fiducial region to CMS' $H \rightarrow WW$ Run 2 differential analysis for…
  - $120\ GeV <\ p_t^H$
  - $N_{Jets} > 2$
  - Leading Jet $p_t > 120\ GeV$
- With $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ$ Analyses there will be good coverage for entire Higgs phase space.

Backup

Correlation, Regularized, PTH



Correlation, Regularized, NJets



Correlation, Regularized, Leading Jet Pt