*HIGGS2022, 7th-11th November 2022, Pisa*

# Progresses in signal and background modelling and recent measurements of background processes from ATLAS and CMS

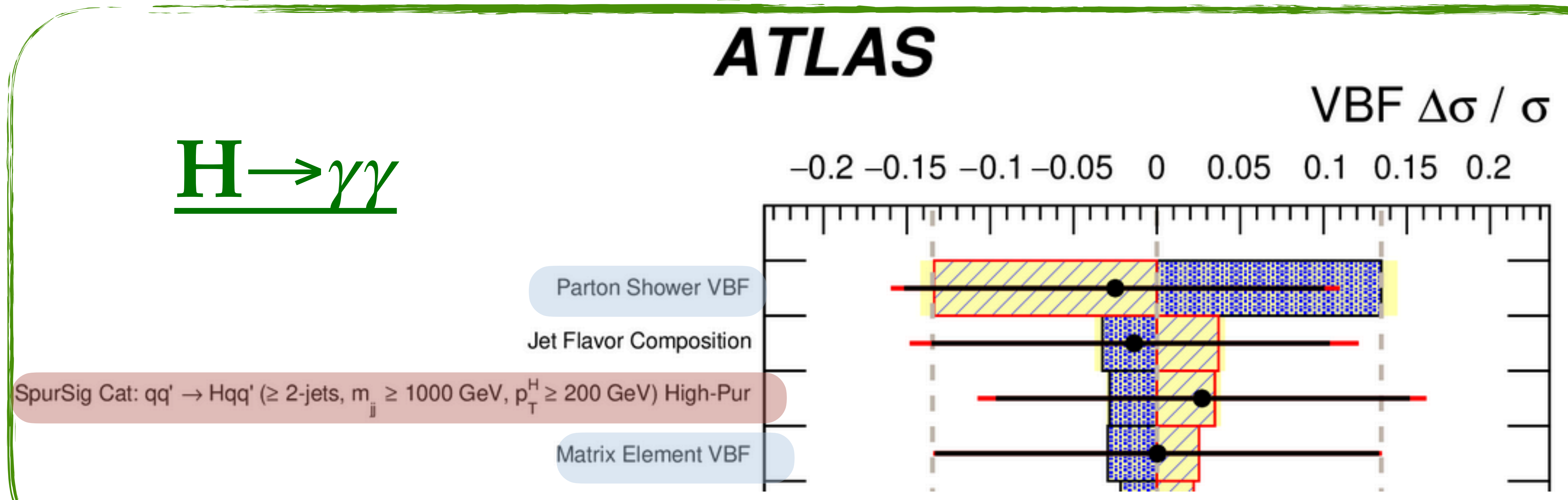
Ana Cueto (CERN)

LHC HIGGS WG

# Overview

## A quite broad topic…

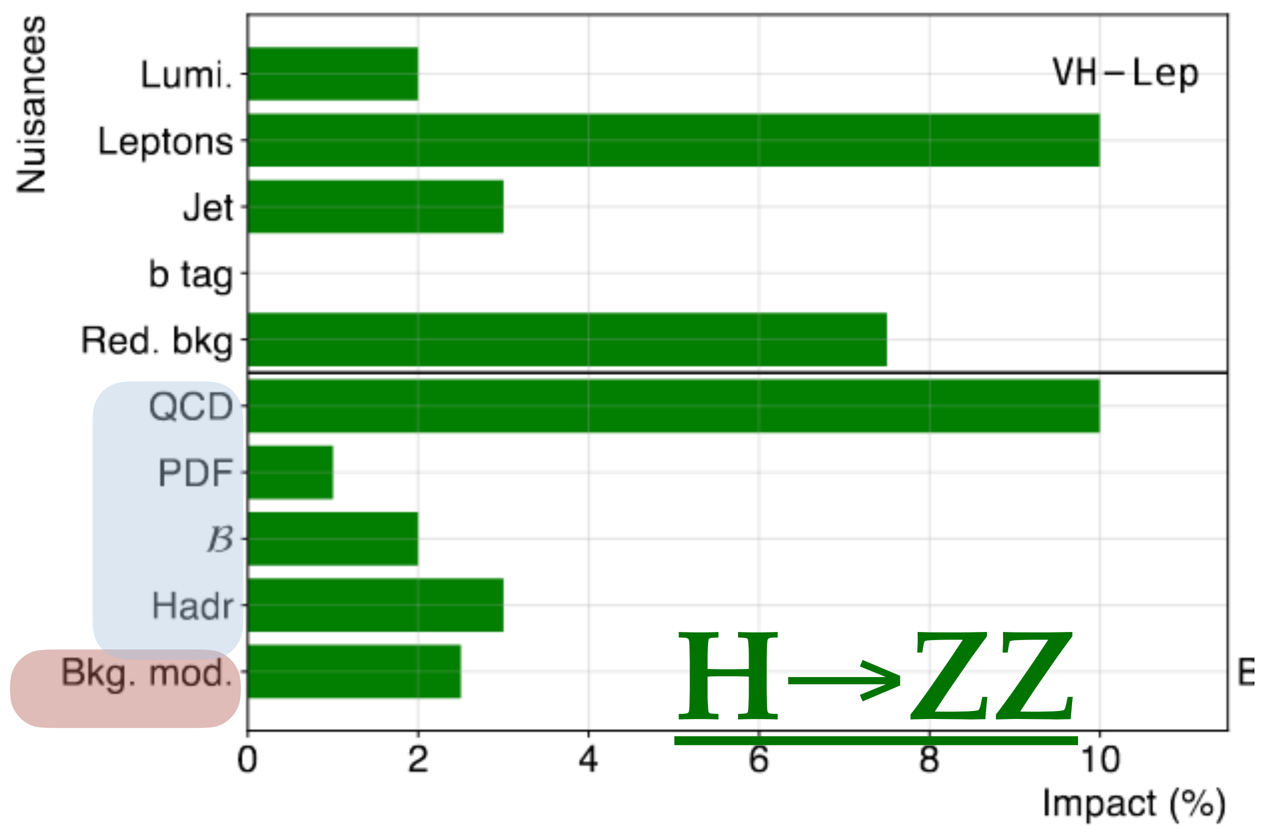
### H→γγ




= signal modelling uncertainty

= background modelling uncertainty

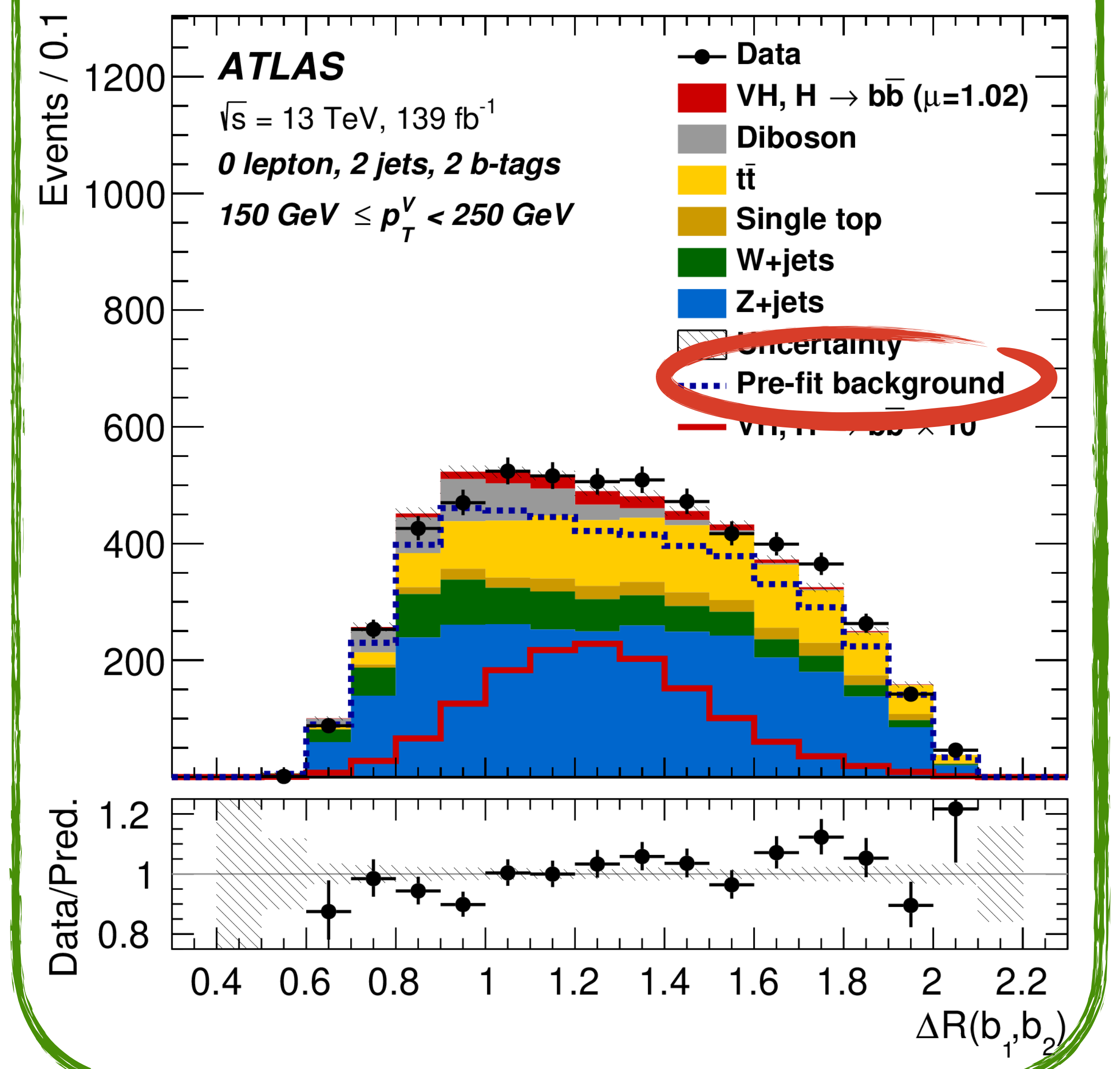
### H→ZZ



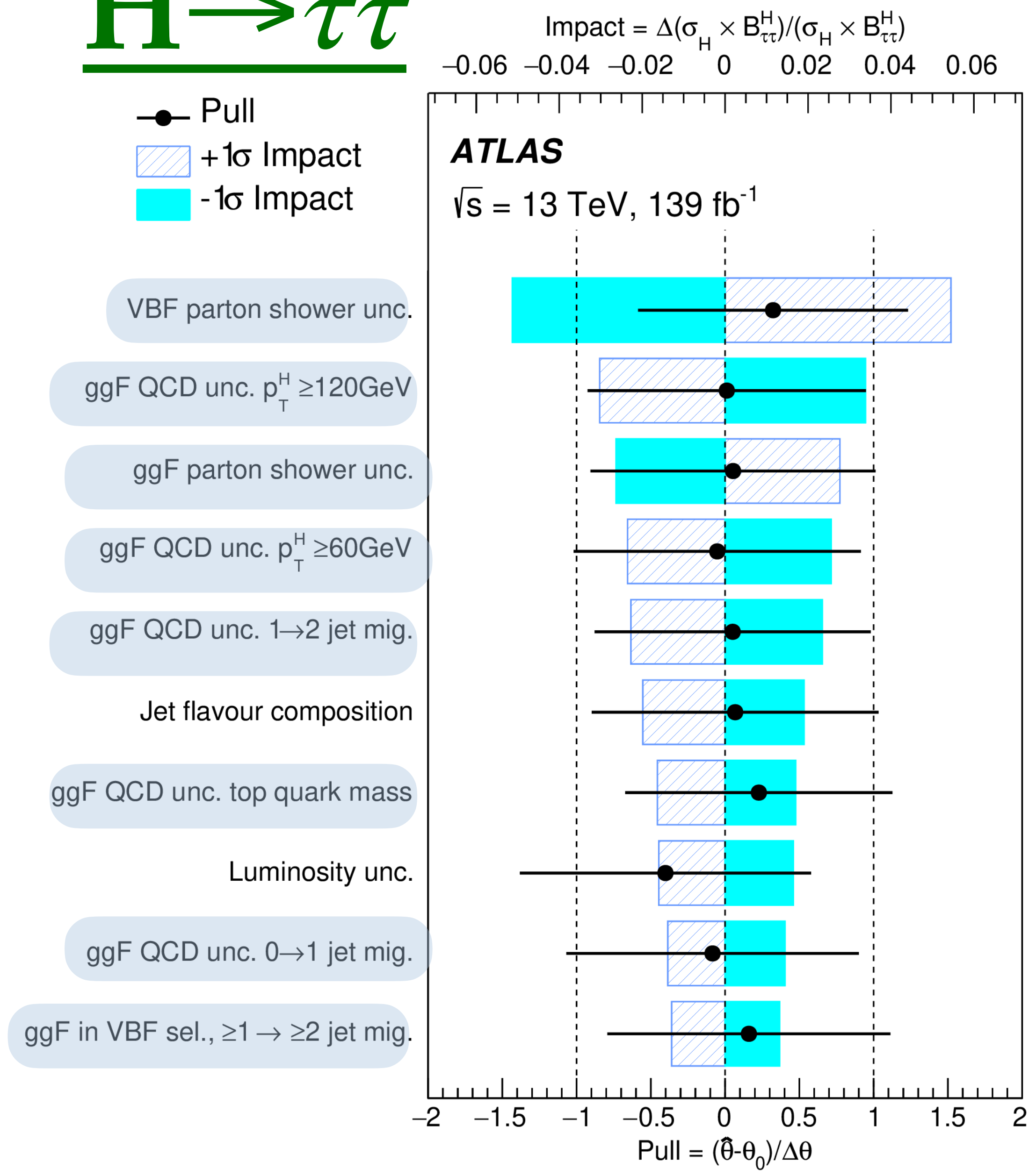

### H→WW

| Source | $\frac{\Delta\sigma_{\text{ggF+VBF}}\cdot\mathcal{B}_{H\to WW^*}}{\sigma_{\text{ggF+VBF}}\cdot\mathcal{B}_{H\to WW^*}}$ [%] | $\frac{\Delta\sigma_{\text{ggF}}\cdot\mathcal{B}_{H\to WW^*}}{\sigma_{\text{ggF}}\cdot\mathcal{B}_{H\to WW^*}}$ [%] | $\frac{\Delta\sigma_{\text{VBF}}\cdot\mathcal{B}_{H\to WW^*}}{\sigma_{\text{VBF}}\cdot\mathcal{B}_{H\to WW^*}}$ [%] |
|---|---|---|---|
| Data statistical uncertainties | 4.6 | 5.1 | 15 |
| Total systematic uncertainties | 9.5 | 11 | 18 |
| Theoretical uncertainties | 6.8 | 7.8 | 16 |
| ggF | 3.8 | 4.3 | 4.6 |
| VBF | 3.2 | 0.7 | 12 |
| $WW$ | 3.5 | 4.2 | 5.5 |
| Top | 2.9 | 3.8 | 6.4 |
| $Z\tau\tau$ | 1.8 | 2.3 | 1.0 |
| Other $VV$ | 2.3 | 2.9 | 1.5 |
| Other Higgs | 0.9 | 0.4 | 0.4 |

### H→bb




### H→ττ



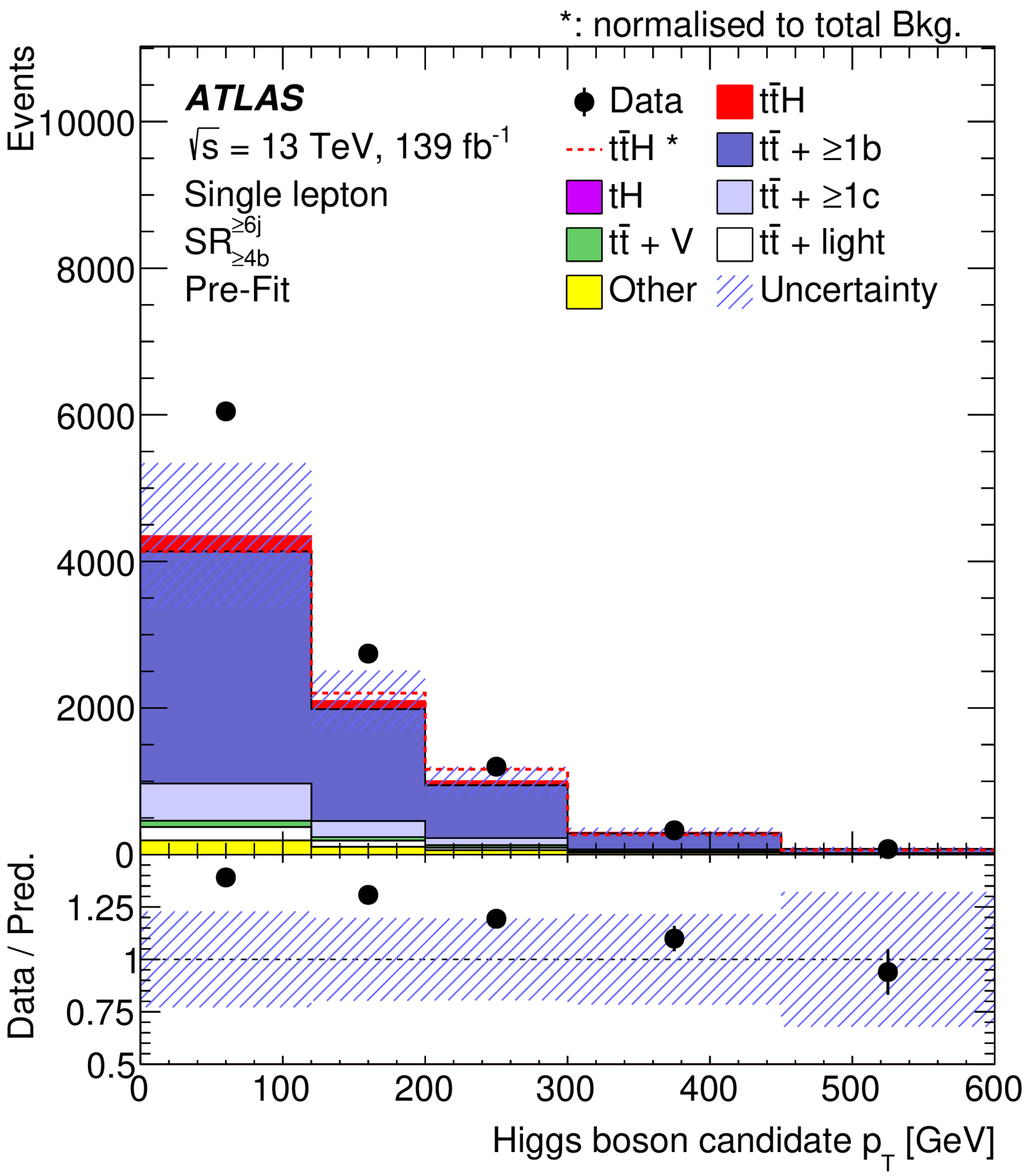

**…focus only on recent studies from experimental collaborations**

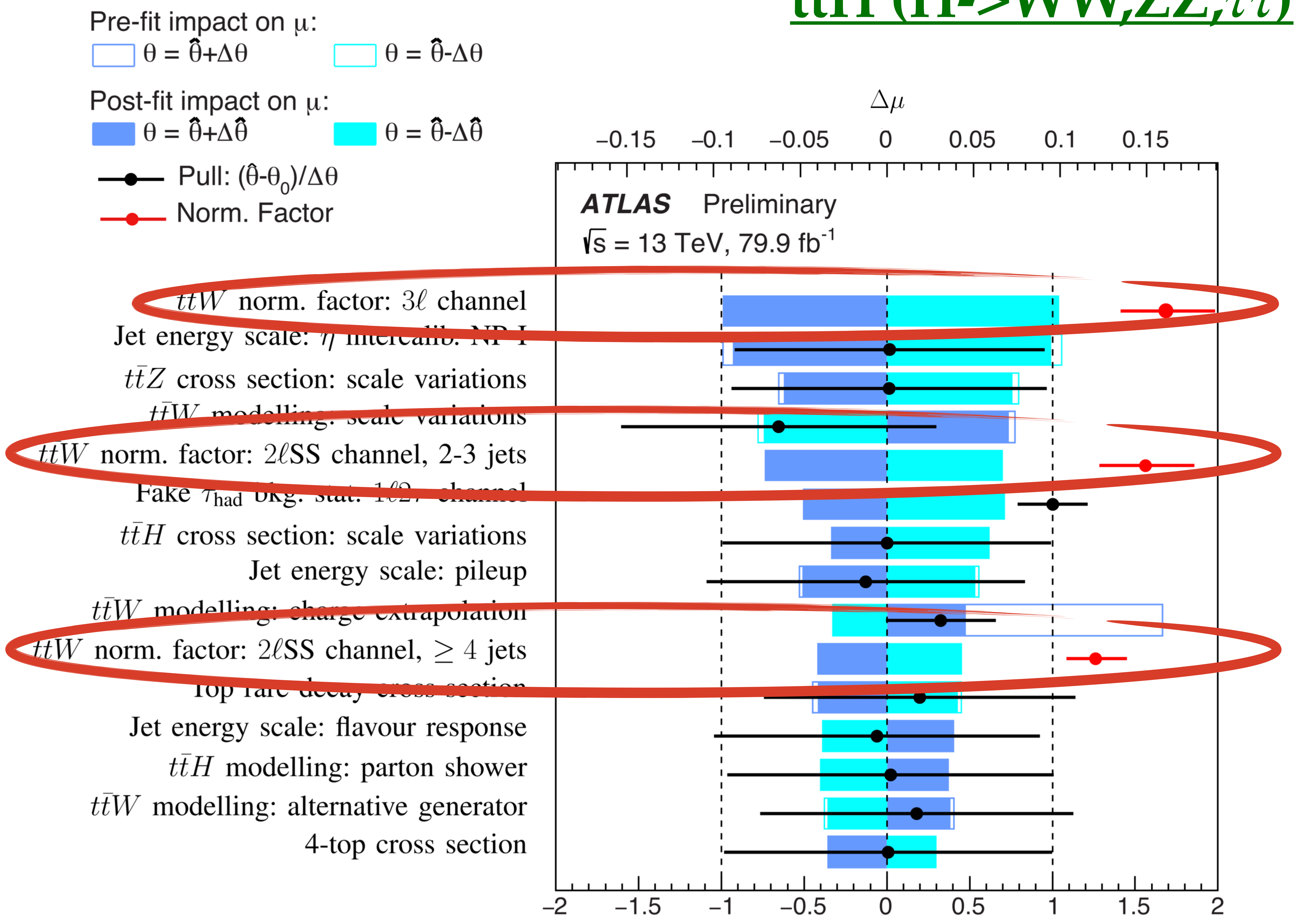
# Overview

## A quite broad topic…

**ttH (H->WW,ZZ,$\tau\tau$)**

**ttH (H->bb)**




## …focus only on recent studies from experimental collaborations

# Outline

BACKGROUNDS

**BACKGROUNDS TO TTH**

- Measurements of ttW
- Progresses in ttW modelling
- Measurements of ttbb
- Progresses in ttbb modelling

SIGNALS

**IN PRESENCE OF BSM EFFECTS**

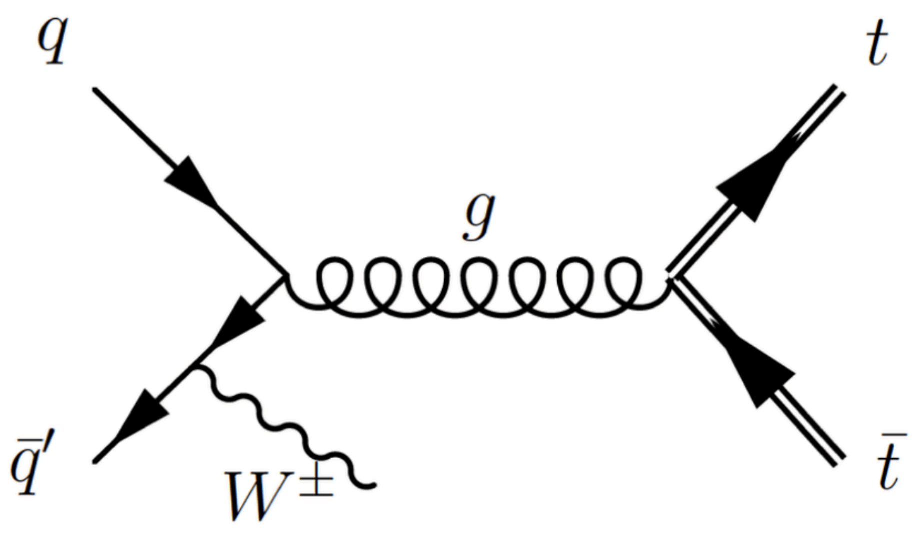
- SMEFT
- Anomalous Higgs trilinear self coupling

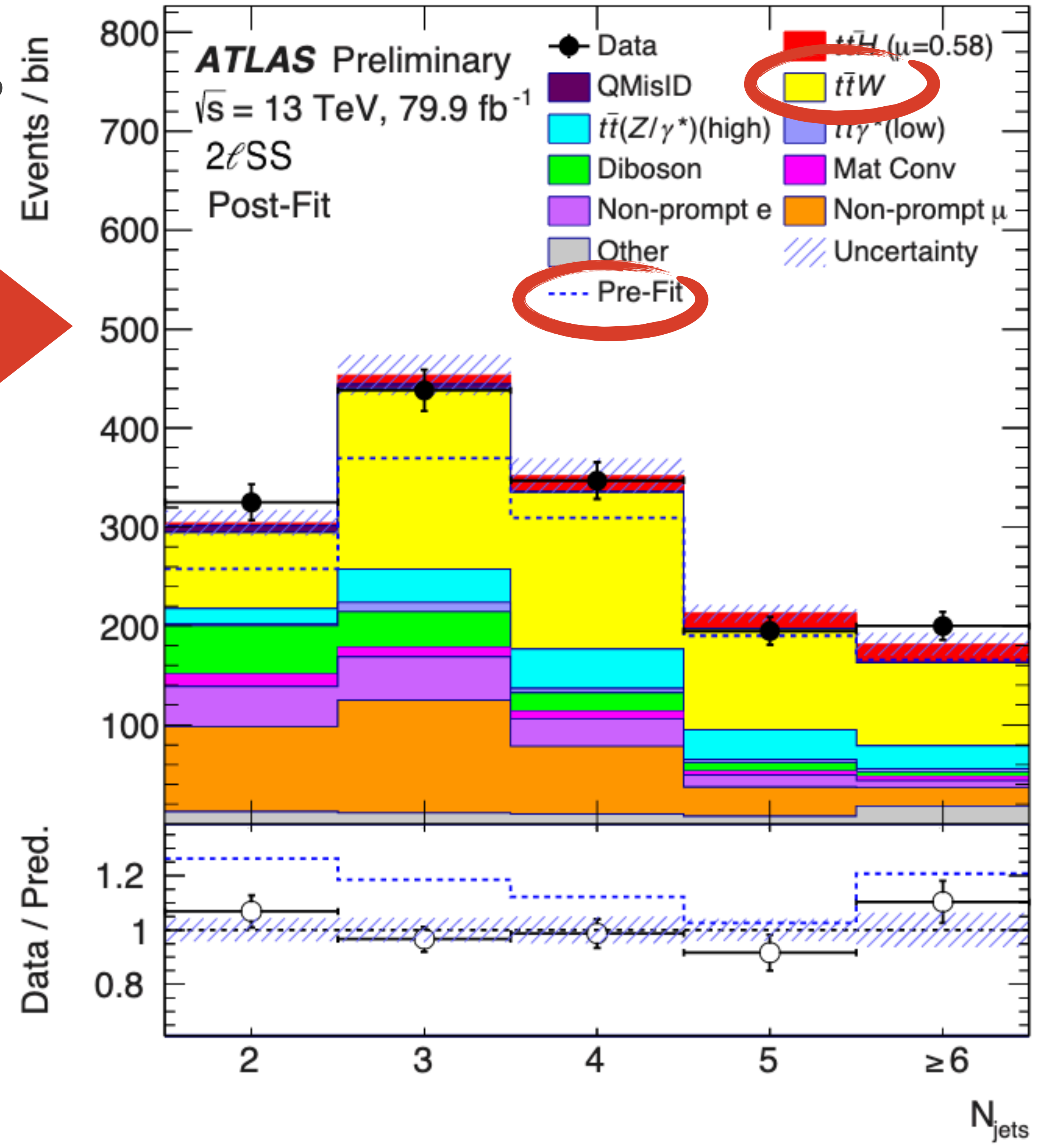
**ONLY SINGLE HIGGS COVERED**

# BACKGROUNDS TO TTH

# Introduction: backgrounds to ttH

- **ttW is the main irreducible background in ttH in multilepton final states**
  - Normalisation factors of ttW background
    $\lambda_{ttW}^{2l,Nj=2,3} = 1.56^{+0.30}_{-0.28}, \lambda_{ttW}^{2l,Nj\geq4} = 1.26^{+0.19}_{-0.18}, \lambda_{ttW}^{3l} = 1.68^{+0.3}_{-0.28}$




ATLAS-CONF-2019-045

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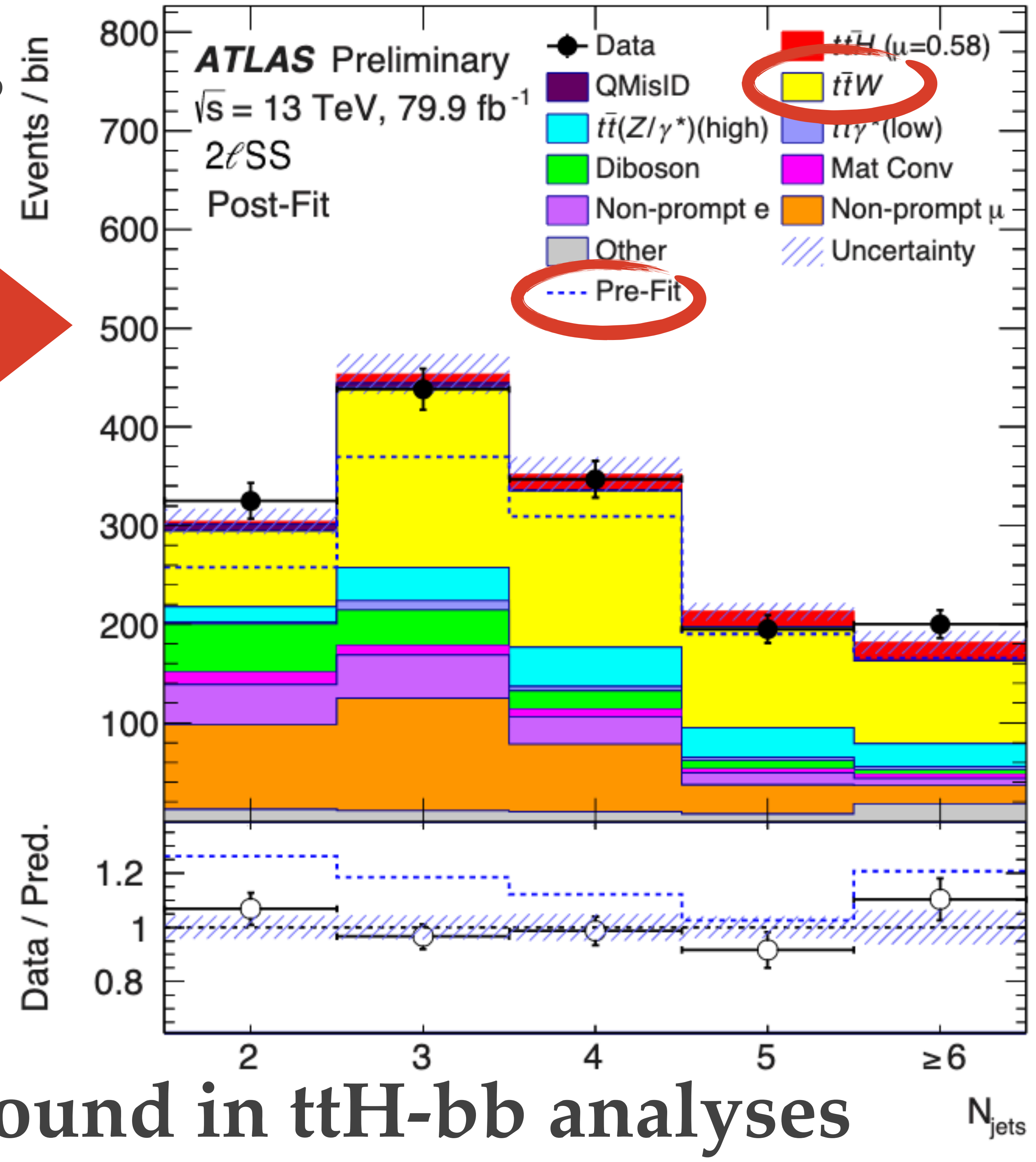


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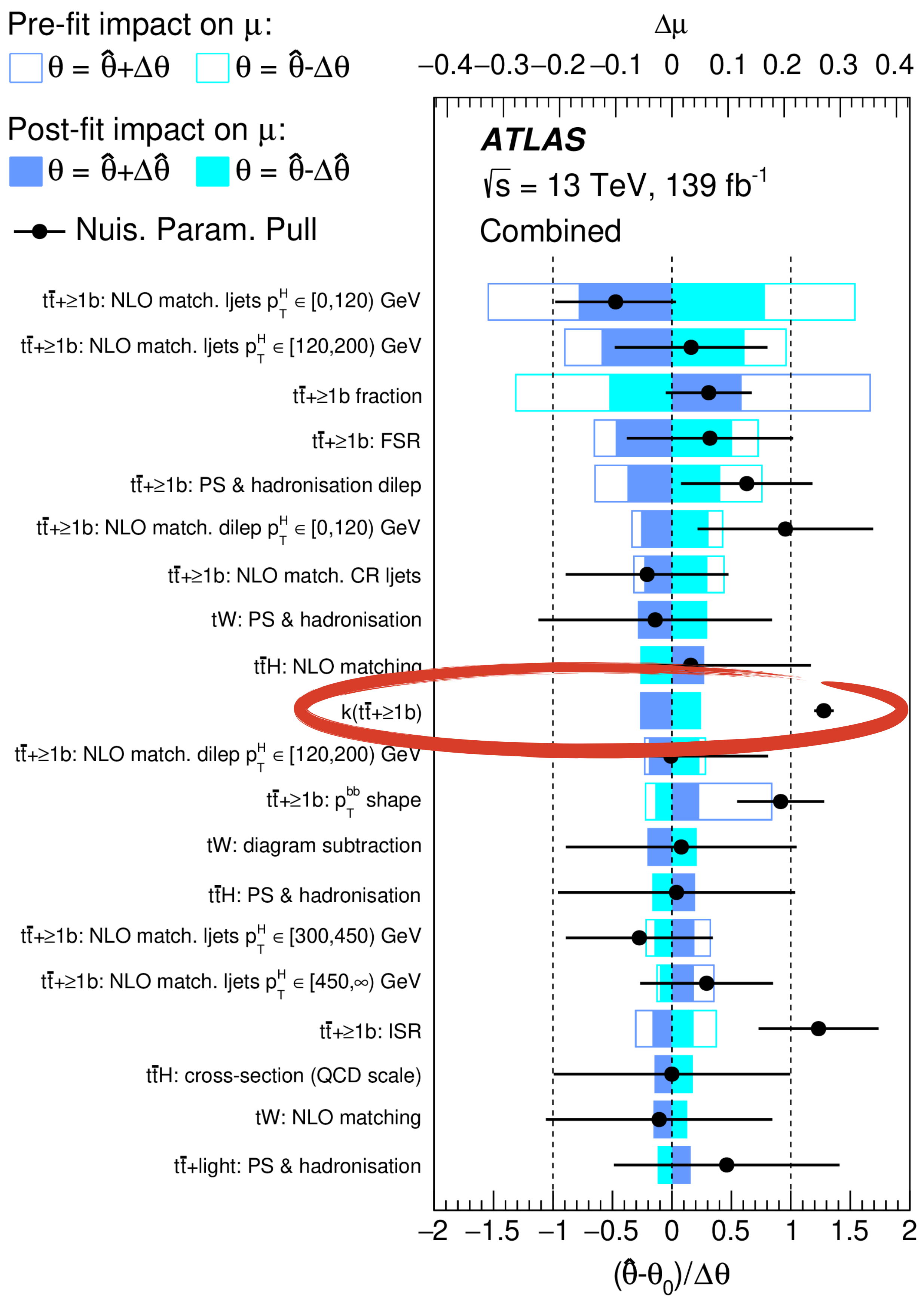


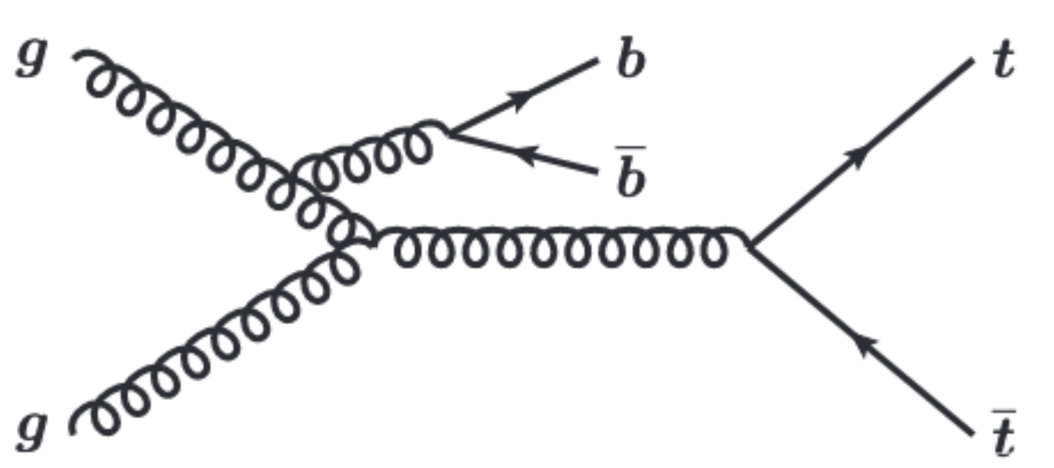


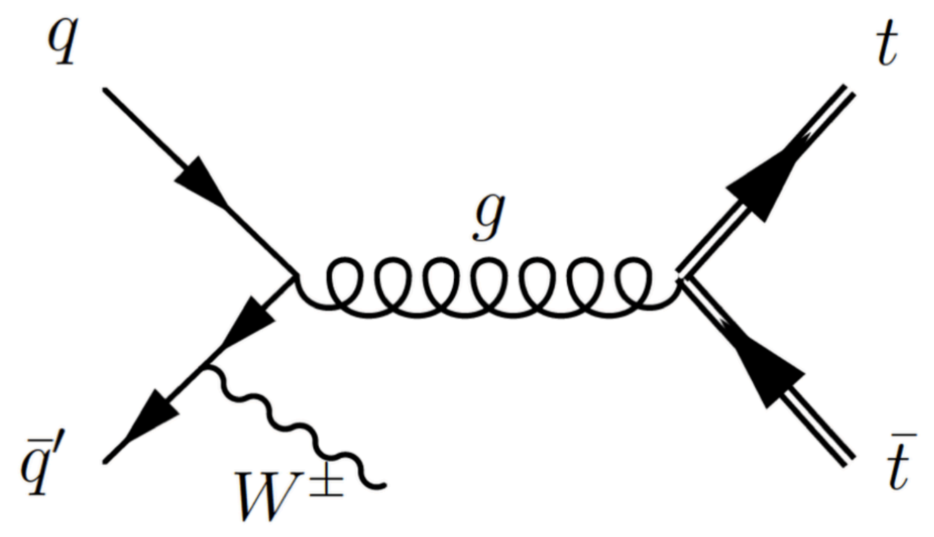


- **ttbb is the main irreducible background in ttH-bb analyses**
  - Observed mismodelling in pTbb and Njets
  - Normalisation factor $tt + \geq 1b = 1.28 \pm 0.08$
  - ttbb modelling limits the measurement

HIGG-2020-23

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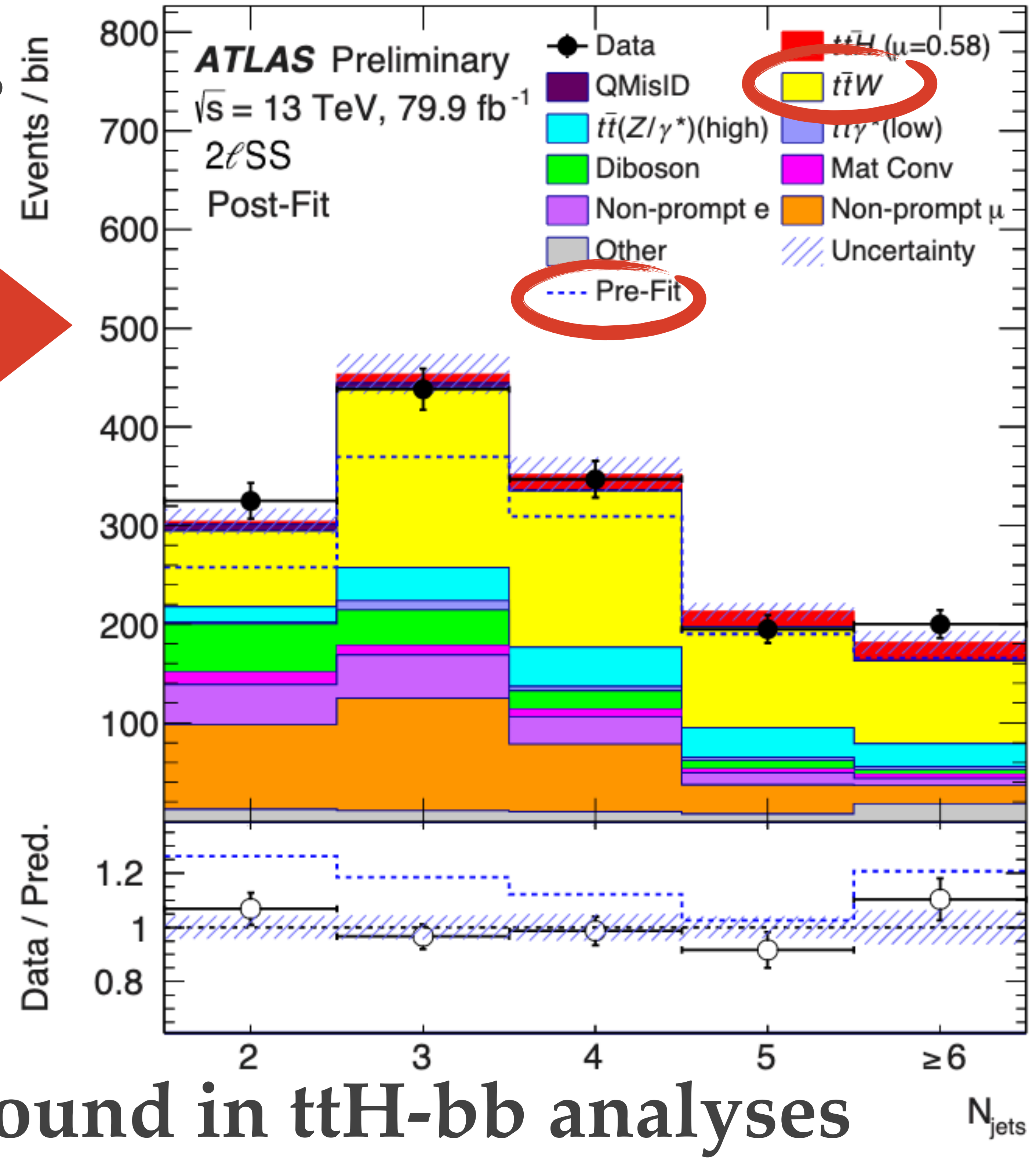


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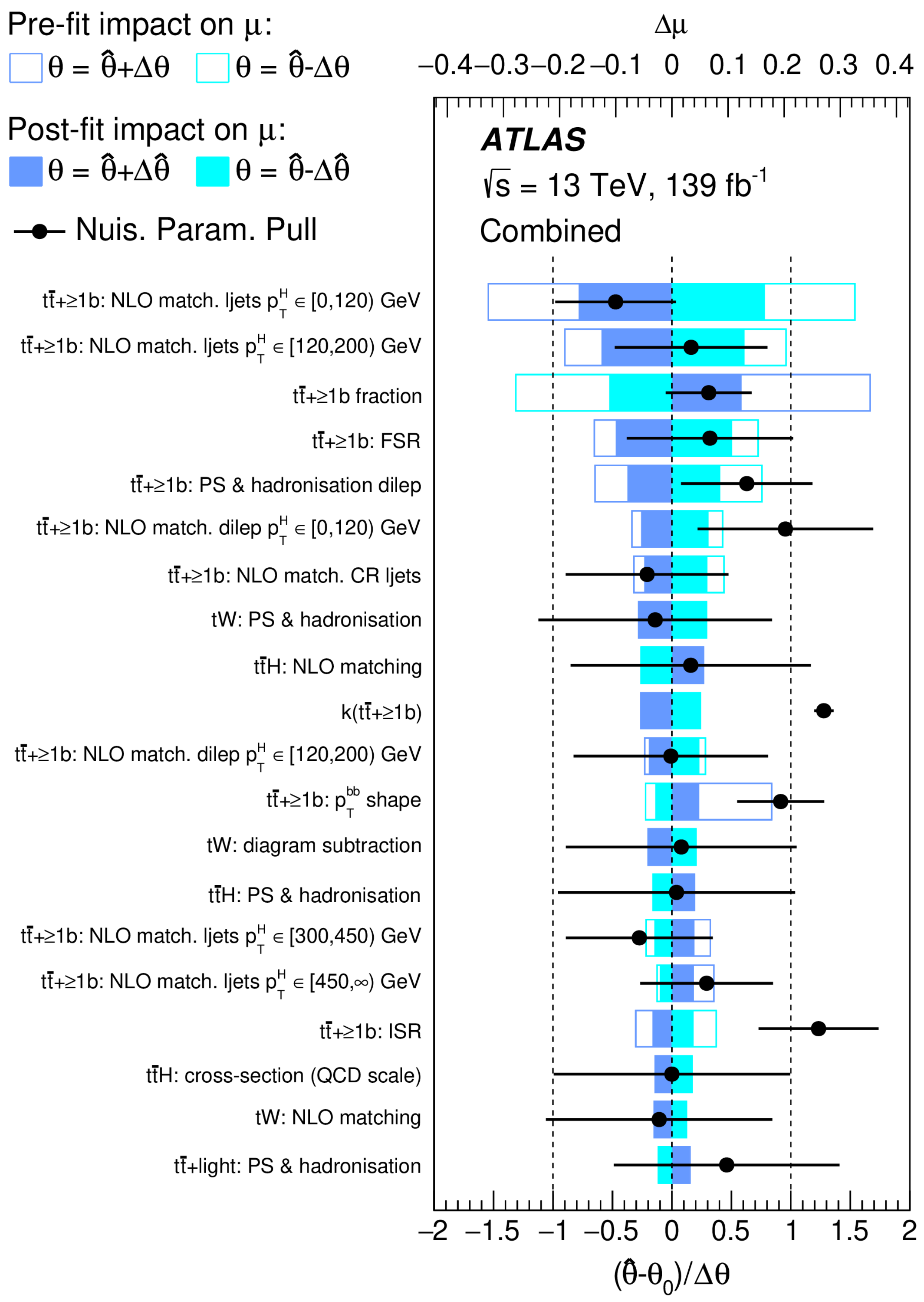


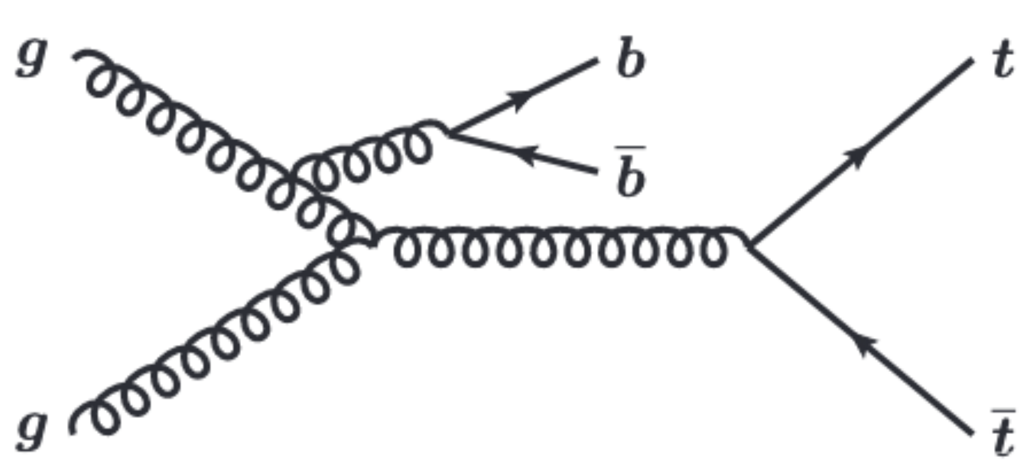


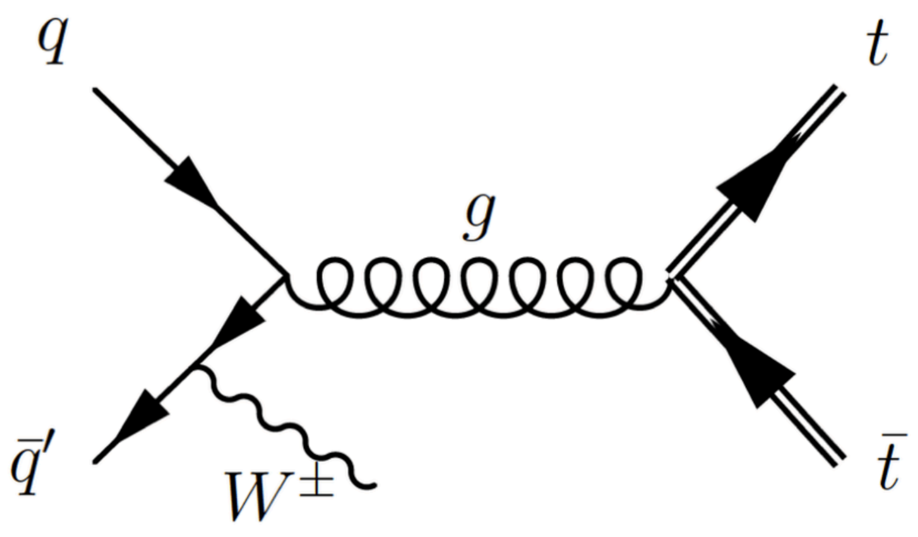


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See talk by Judith for more details

**Measurements needed to test higher-order predictions!**

**Need to agree on how modelling uncertainties are treated in ttH!**

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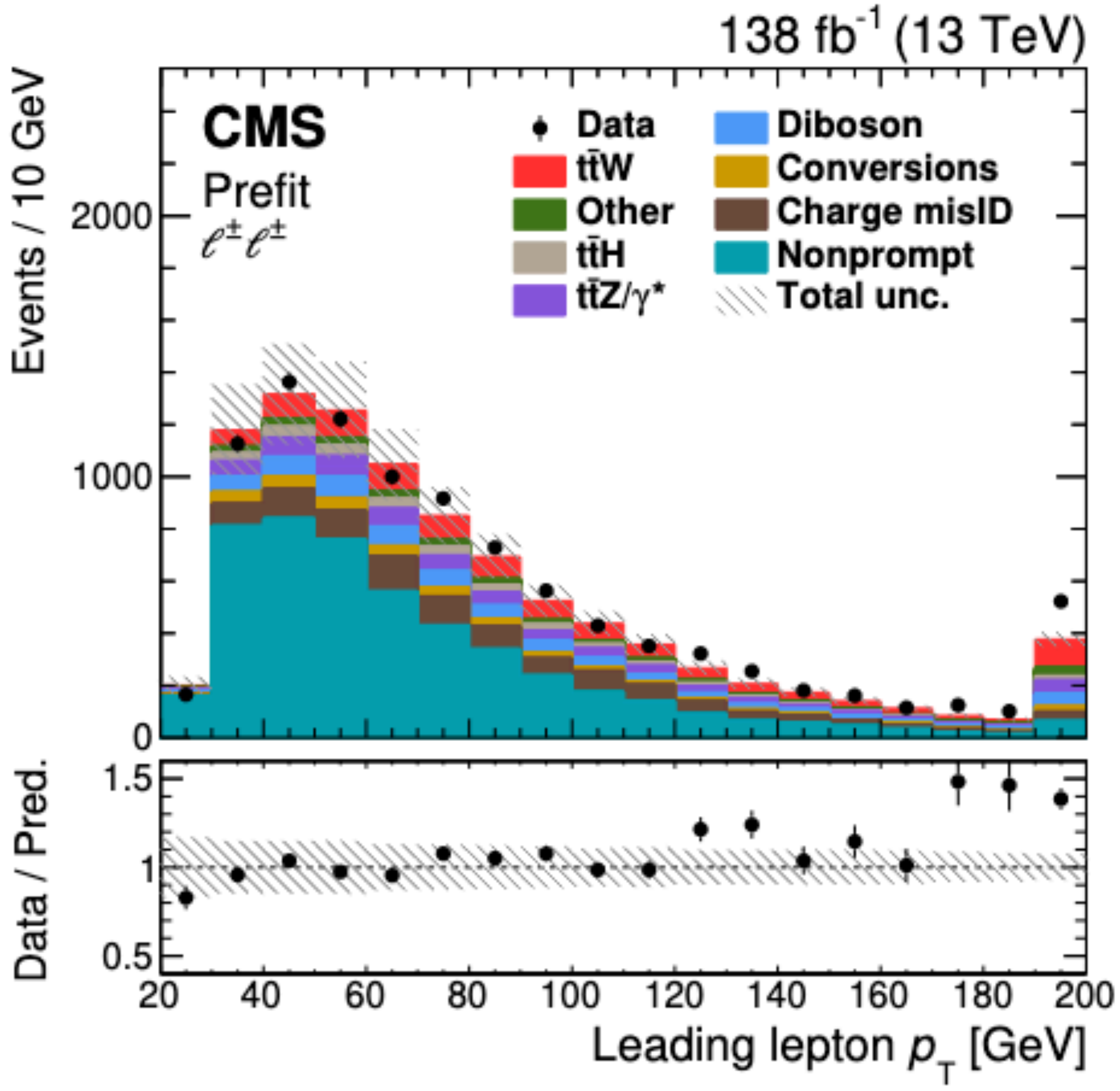
# Measurement of ttW

TOP-21-011

- Inclusive cross section measurement of ttW
  - 2 channels: 2SS leptons, or 3 leptons
- Irreducible backgrounds: dominated by ttZ and ttH
- Reducible backgrounds: dominated by non-prompt leptons
- Final results from a profiled likelihood fit to data in NN-score trained to suppressed the background or m(3l)

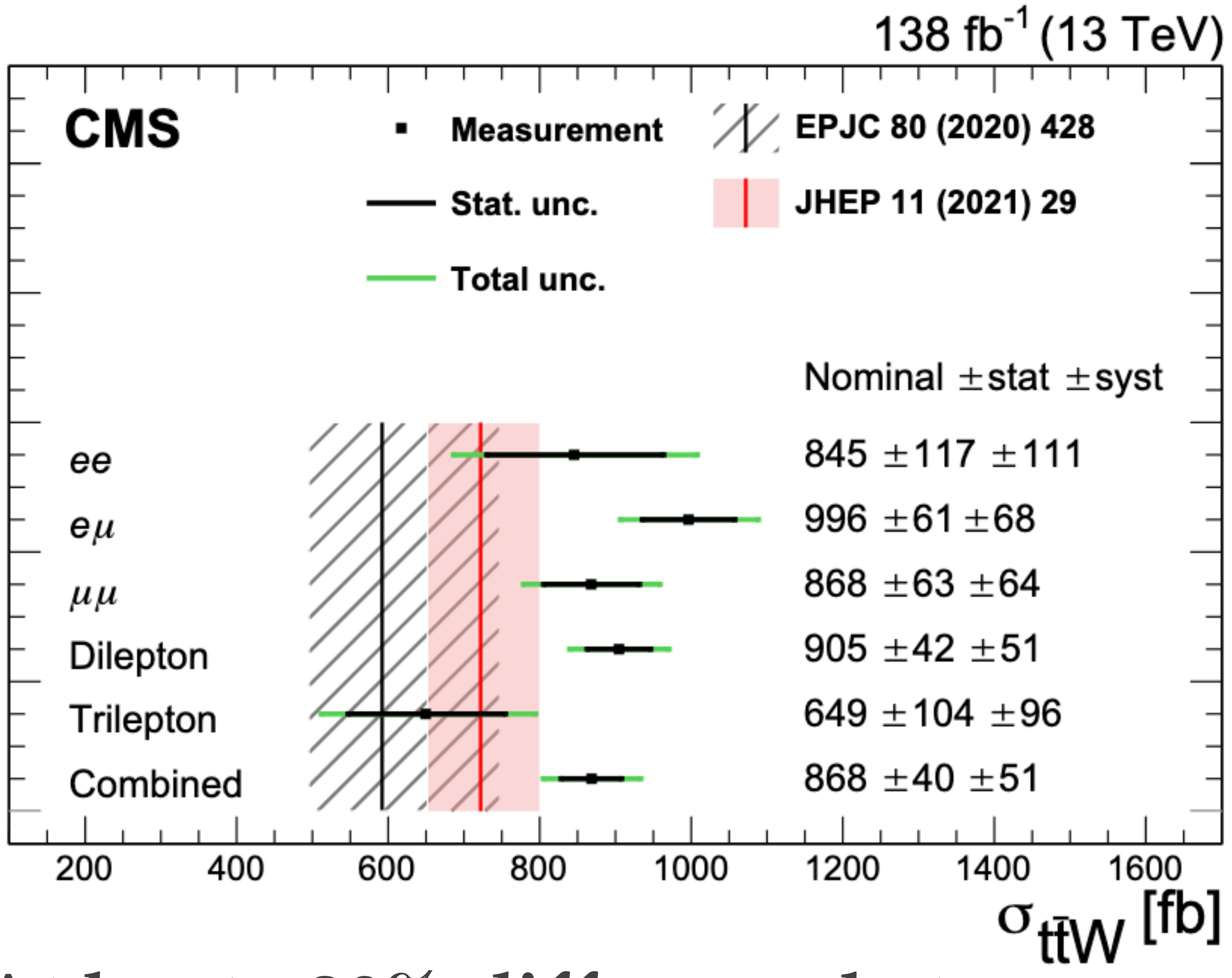


# Measurement of ttW

TOP-21-011

| Source | Uncertainty [%] |
|---|---|
| Experimental uncertainties | |
| Integrated luminosity | 1.9 |
| b tagging efficiency | 1.6 |
| Trigger efficiency | 1.2 |
| Background uncertainties | |
| $t\bar{t}$H normalization | 2.6 |
| Charge misidentification | 1.6 |
| Nonprompt leptons | 1.3 |
| VVV normalization | 1.2 |
| $t\bar{t}$VV normalization | 1.2 |
| Modeling uncertainties | |
| $t\bar{t}$W scale | 1.8 |
| $t\bar{t}$W color reconnection | 1.0 |
| Simulation statistical uncertainty | 1.8 |
| Total systematic uncertainty | 5.8 |

| Observable | Measurement | SM prediction NLO + NNLL | NLO + FxFx |
|---|---|---|---|
| $\sigma_{t\bar{t}W}$ | $868 \pm 40\,(\text{stat}) \pm 51\,(\text{syst})$ fb | $592\,^{+155}_{-97}\,(\text{theo})$ fb | $722\,^{+71}_{-78}\,(\text{theo})$ fb |
| $\sigma_{t\bar{t}W+}$ | $553 \pm 30\,(\text{stat}) \pm 30\,(\text{syst})$ fb | $384\,^{+53}_{-33}\,(\text{theo})$ fb | $475\,^{+46}_{-52}\,(\text{theo})$ fb |
| $\sigma_{t\bar{t}W-}$ | $343 \pm 26\,(\text{stat}) \pm 25\,(\text{syst})$ fb | $198\,^{+26}_{-17}\,(\text{theo})$ fb | $247\,^{+24}_{-27}\,(\text{theo})$ fb |
| $\sigma_{t\bar{t}W+}/\sigma_{t\bar{t}W-}$ | $1.61 \pm 0.15\,(\text{stat})\,^{+0.07}_{-0.05}\,(\text{syst})$ | $1.94\,^{+0.37}_{-0.24}\,(\text{theo})$ | $1.92\,^{+0.27}_{-0.29}\,(\text{theo})$ |




* **At least ~20% difference between predictions and measurement (NLO+FxFx better than NLO+NNLL)**

# Progresses in ttW modelling

ATL-PHYS-PUB-2022-026

LHCHWG-2022-003

- Recent progresses in the simulation of ttW
  - ttW+jj corrections can be large ⇒ Needs NLO merged calculations
  - tW scattering contributions to ttWj process ⇒ $\alpha^3\alpha_s$ and $\alpha^2\alpha_s^2$ corrections relevant

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  - ttW+jj corrections can be large ⇒ Needs NLO merged calculations
  - tW scattering contributions to ttWj process ⇒ $\alpha^3\alpha_s$ and $\alpha^2\alpha_s^2$ EW NLO corrections relevant
- Comparisons of generator setups from ATLAS and CMS to agree on an uncertainty scheme

= baseline in each collaboration

| Label | ATLAS Sherpa 2.2.10 | ATLAS Sherpa 2.2.10 QCD+EW | ATLAS MG5_aMC+Py8 FxFx | ATLAS MG5_aMC+Py8 | CMS MG5_aMC+Py8 FxFx |
|---|---|---|---|---|---|
| Process | $t\bar{t}W$ inclusive | $t\bar{t}W$ inclusive | $t\bar{t}W$ inclusive | $t\bar{t}W$ inclusive | $t\bar{t}\ell\nu$ ($t\bar{t}W$ inclusive) |
| Generator | SHERPA 2.2.10 [27] | SHERPA 2.2.10 [27] | MG5_AMC@NLO 2.9.3 [67] | MG5_AMC@NLO 2.3.3 [68] | MG5_AMC@NLO 2.4.2 |
| order of QCD ME | 0,1 $j$@NLO[a] | 0,1 $j$@NLO[a] | 0,1 $j$@NLO | NLO | 0,1 $j$@NLO |
| ME or core scale | $\mu_R = \mu_F = H_T/2$ | $\mu_R = \mu_F = H_T/2$ | dynamic scale choice [24] [65] [66] | $\mu_R = \mu_F = H_T/2$ | dynamic scale choice [24] [65] [66] |
| order of EW corr. | - | $\alpha^3$, $\alpha^2\alpha_s^2$, $\alpha^3\alpha_s$ | - | - | - |
| Parton Shower | SHERPA 2.2.10 | SHERPA 2.2.10 | PYTHIA 8.245 [8] | PYTHIA 8.210 [8] | PYTHIA 8.226 |
| Merging Scheme | MEPs@NLO [62] | MEPs@NLO [62] | FxFx [24] | - | FxFx |
| Merging Scale | 30 GeV | 30 GeV | 30 GeV | - | 42 GeV |
| PDF | NNPDF3.0 NNLO [69] | NNPDF3.0 NNLO | NNPDF3.0 NLO | NNPDF3.0 NLO | NNPDF3.1 NLO [70] |
| Tune | SHERPA default | SHERPA default | A14 [33] | A14 | CP5 [34] |
| Cross section[b] | 597 fb | 615 fb | 613 fb | 548 fb | 220 fb (666 fb[c]) |

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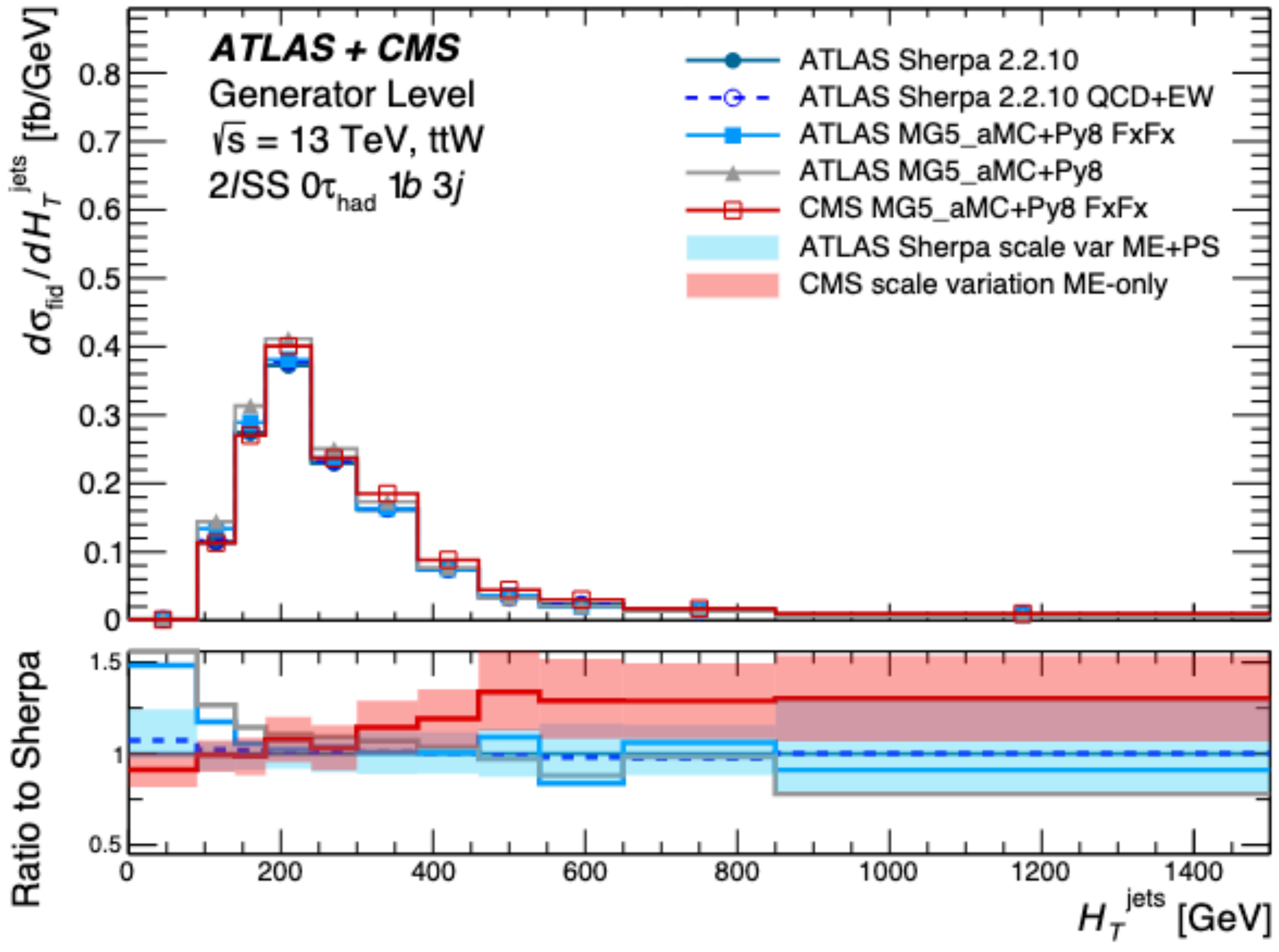
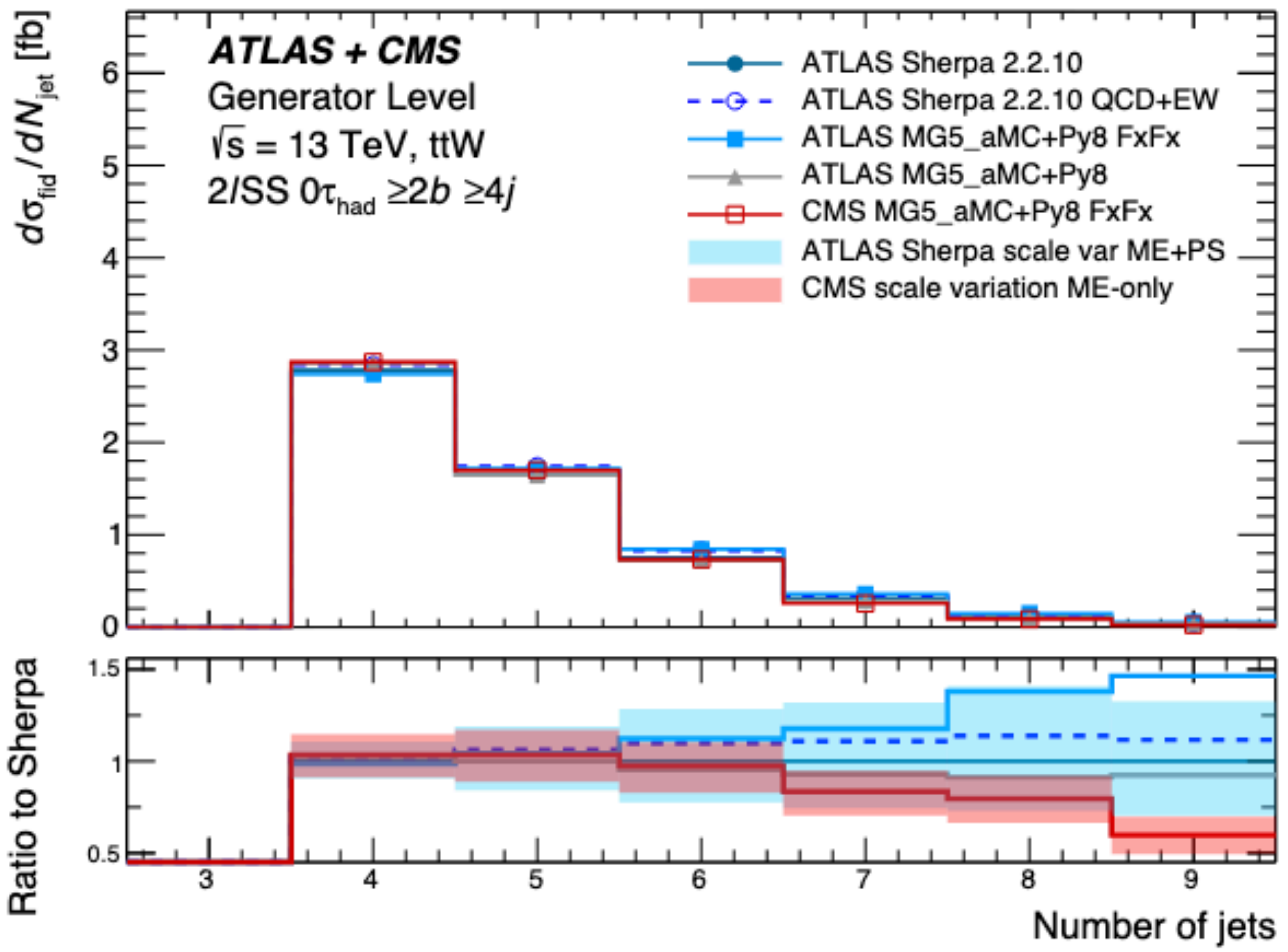



Predictions normalised to YR4 cross section, 600.8 fb

Except for Sherpa, normalised to generator prediction: 614.7 fb



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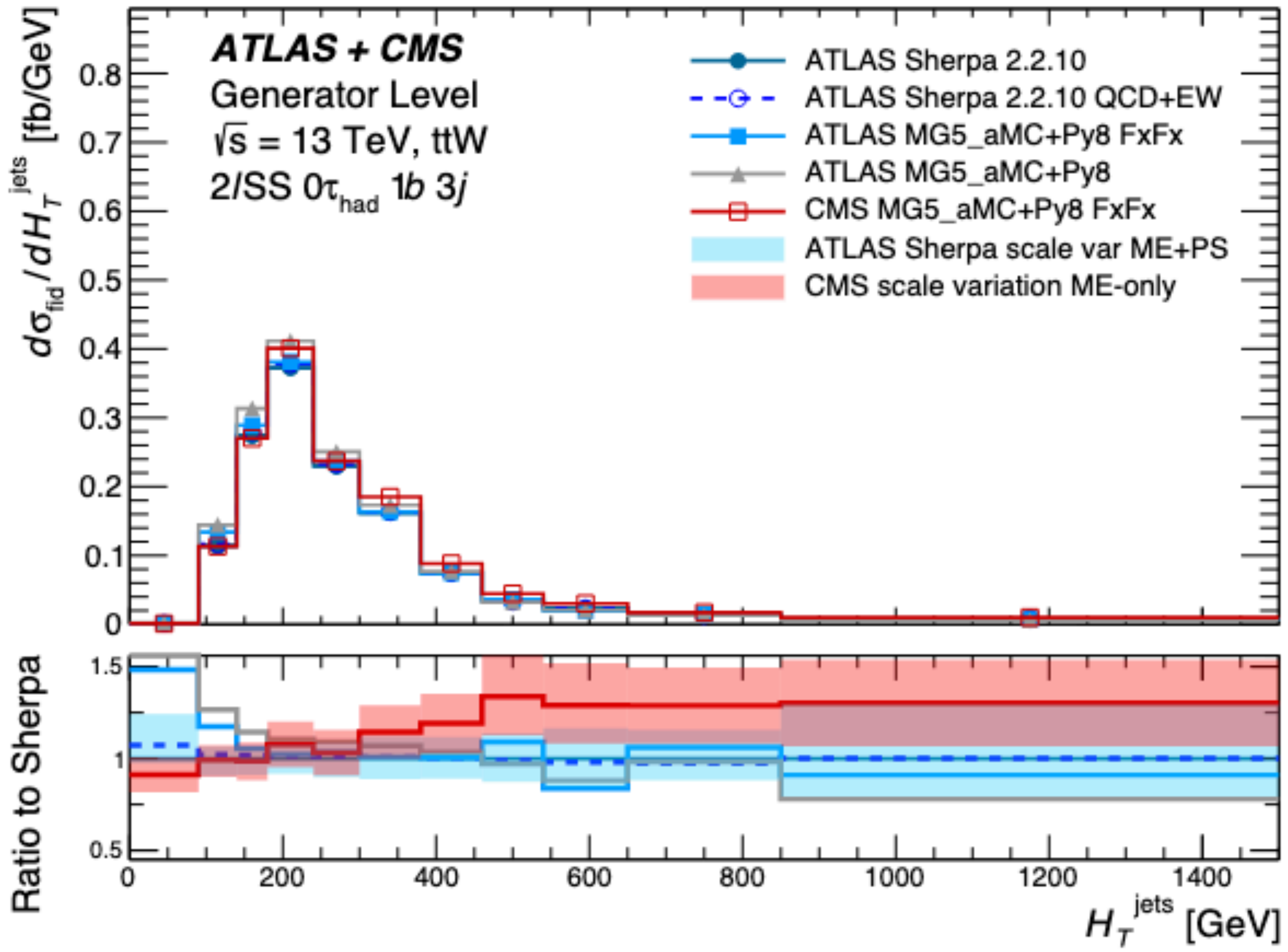


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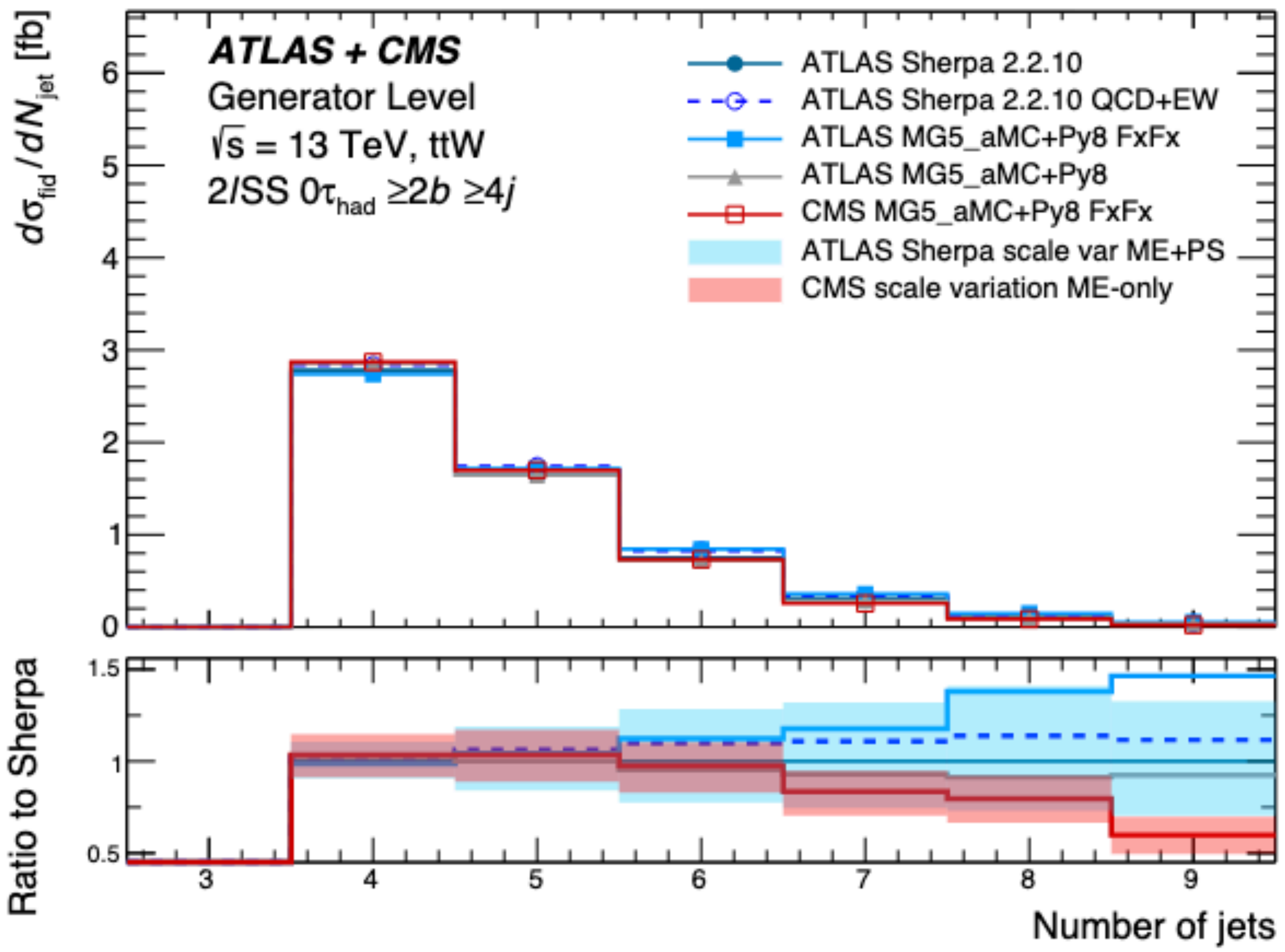


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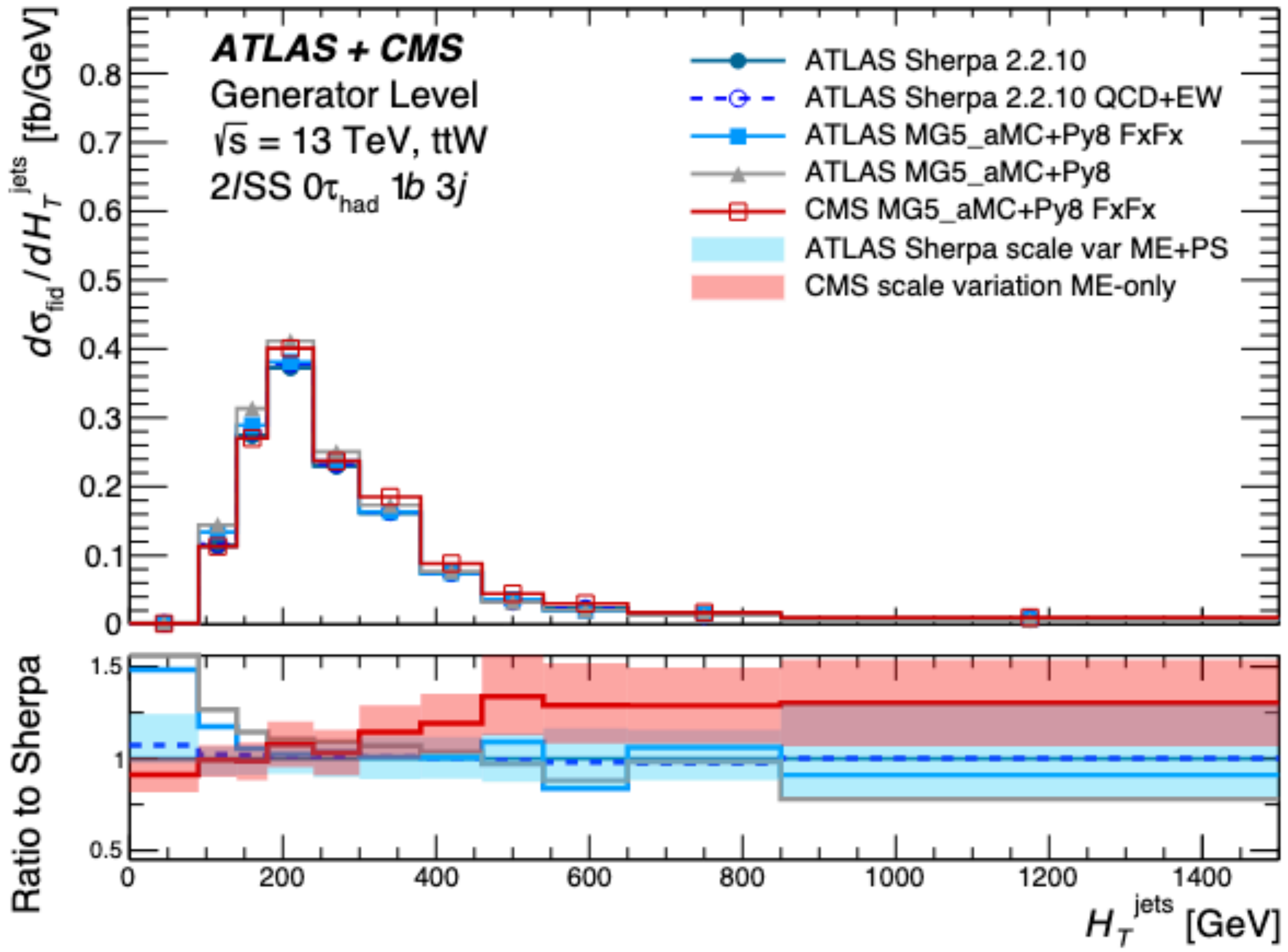


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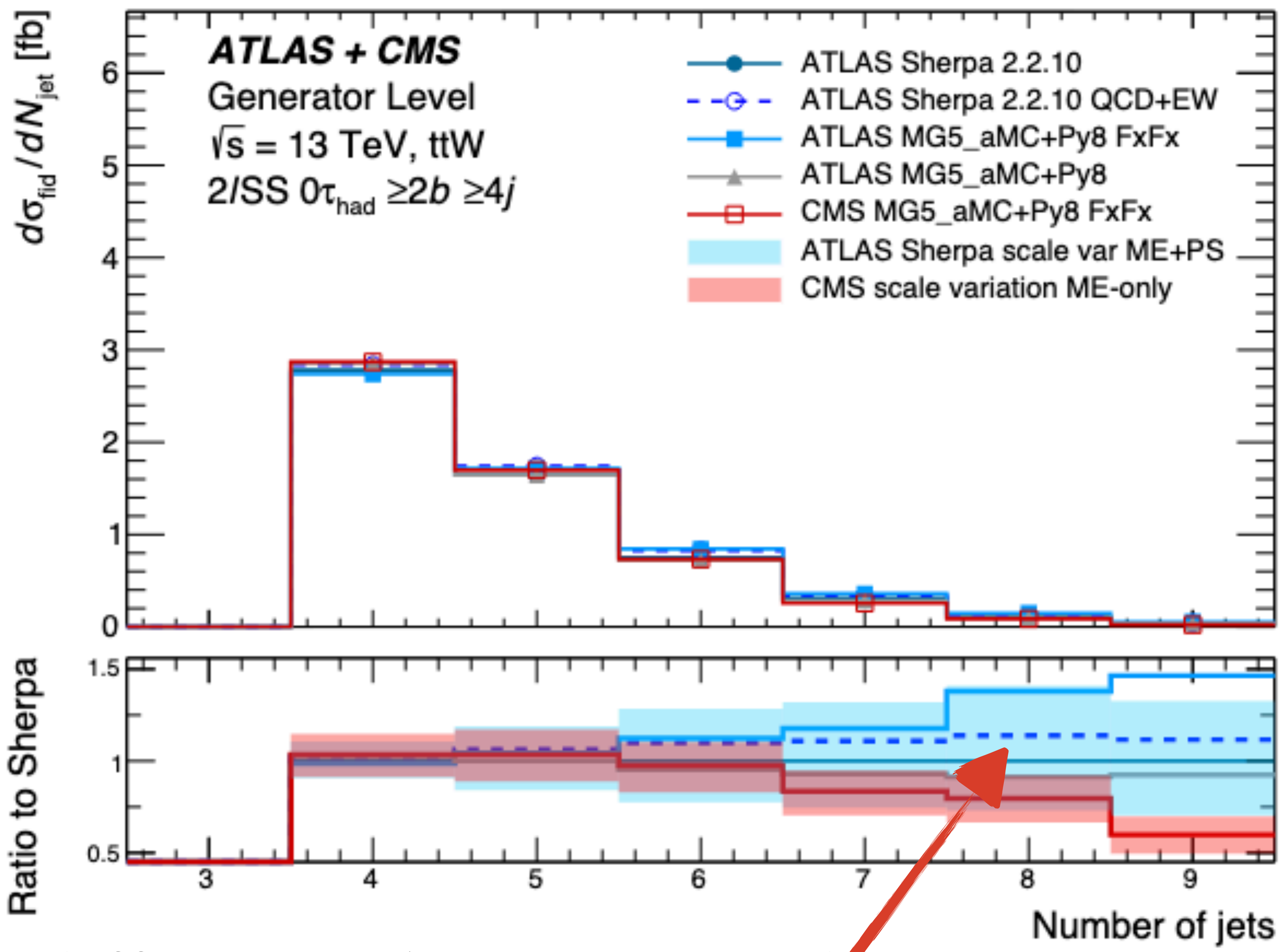


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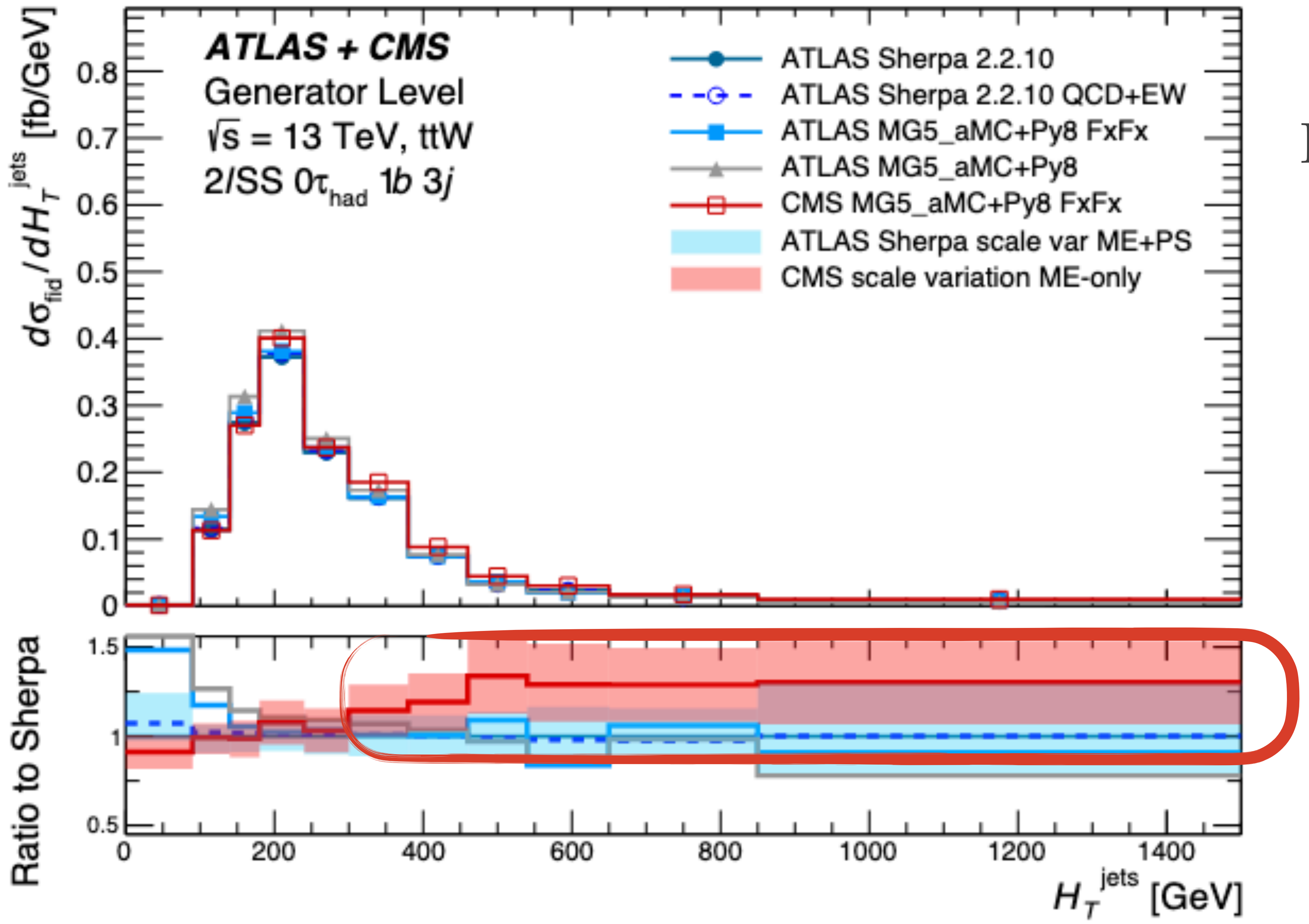


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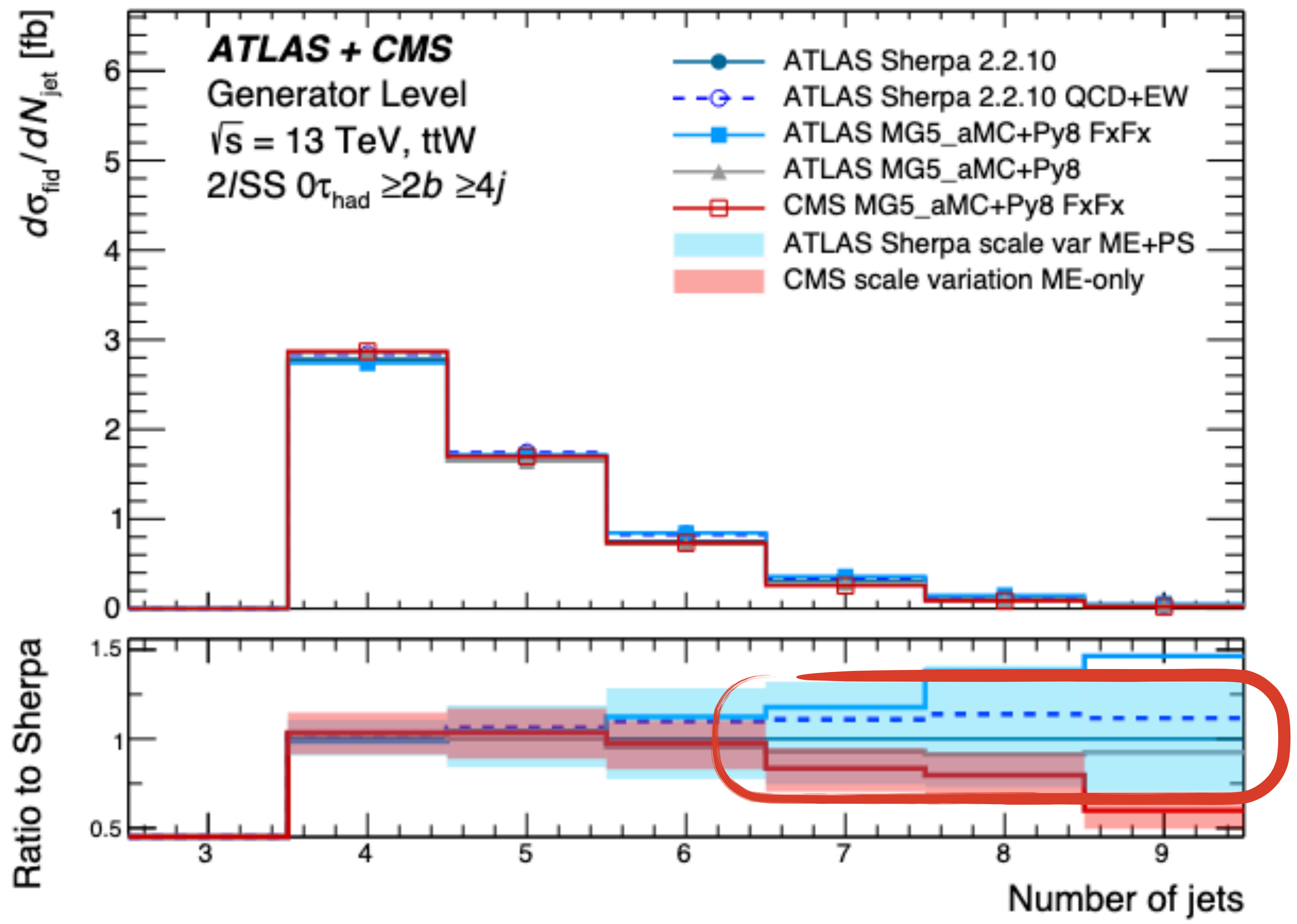


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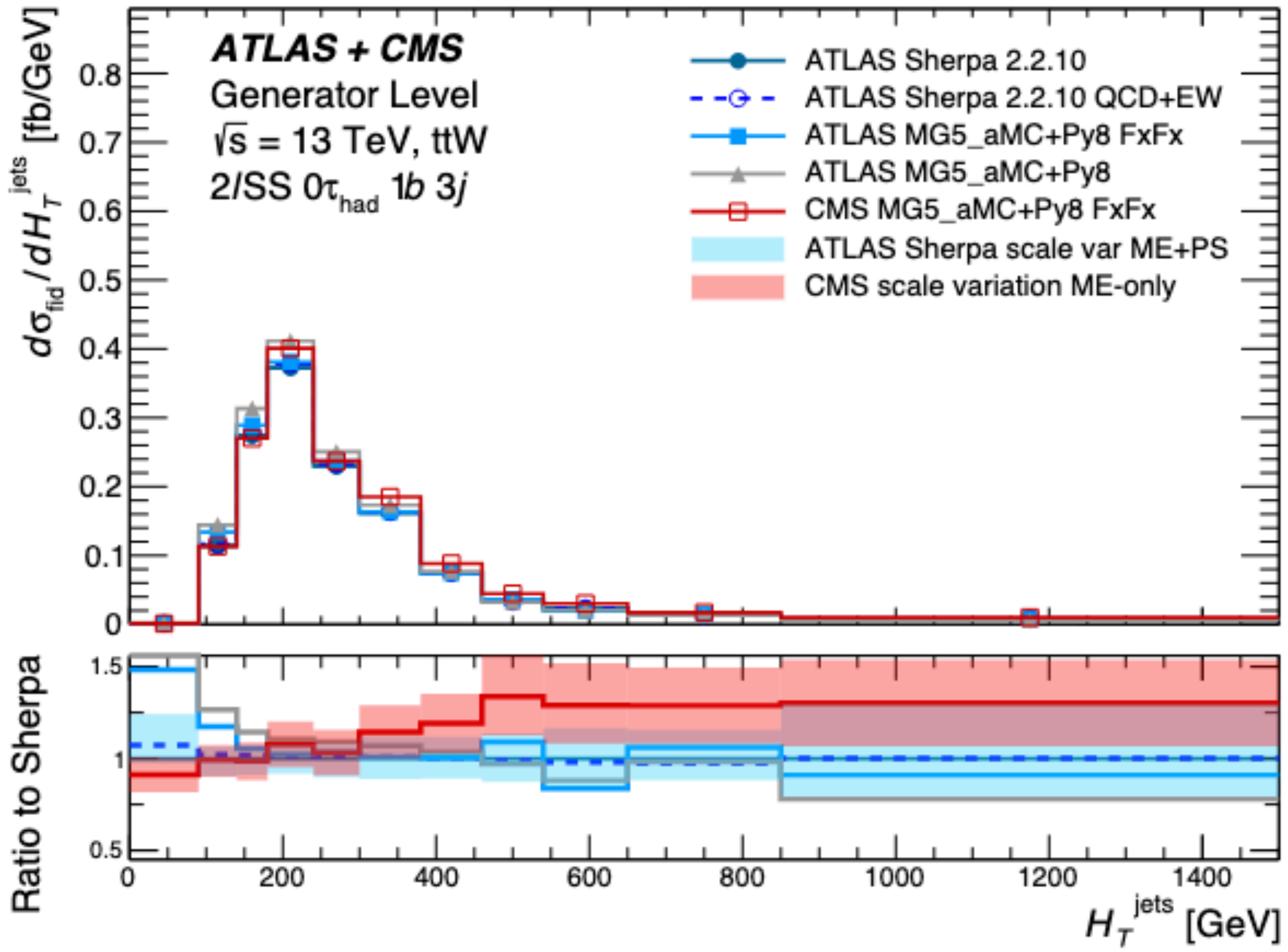


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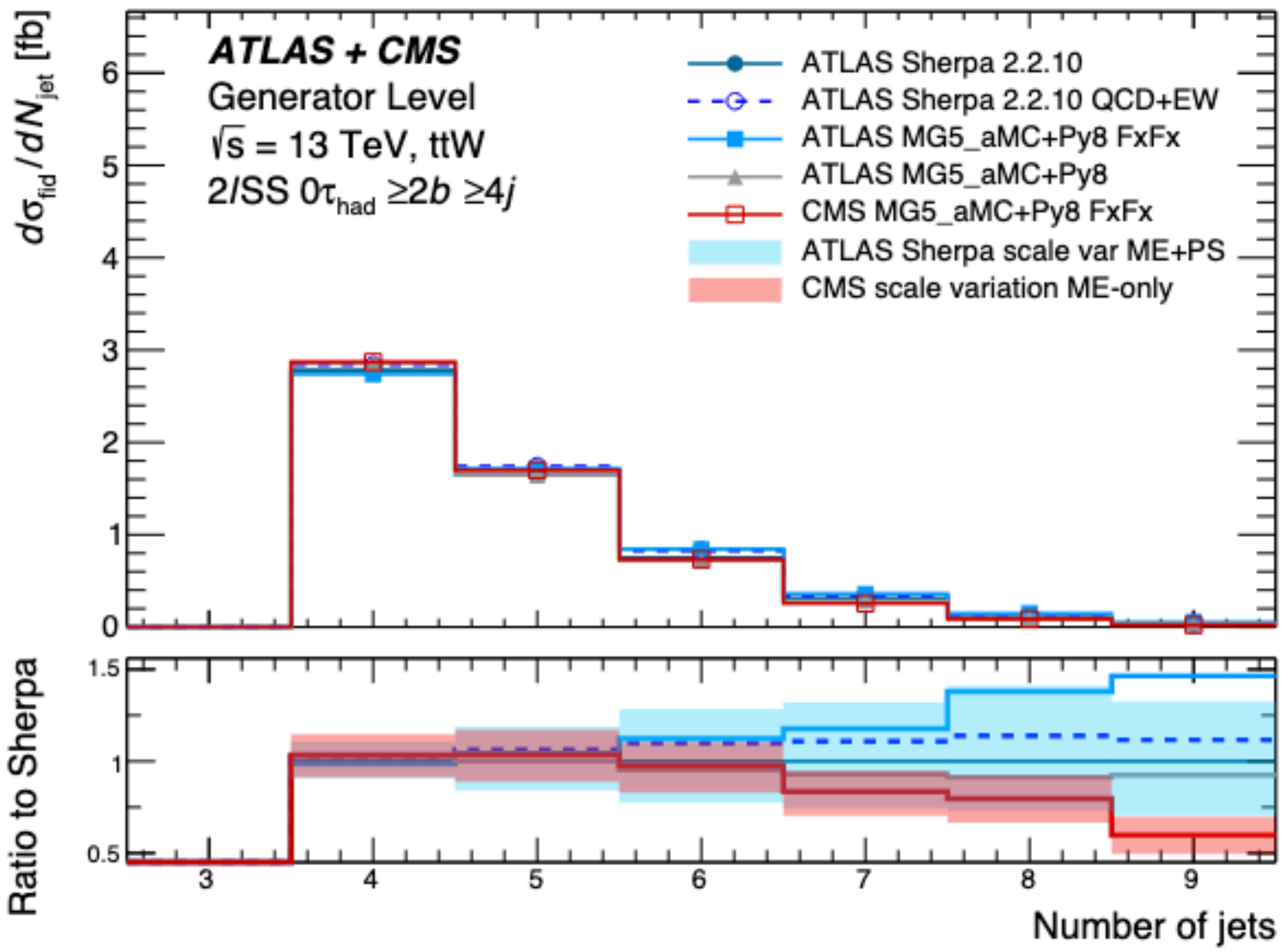


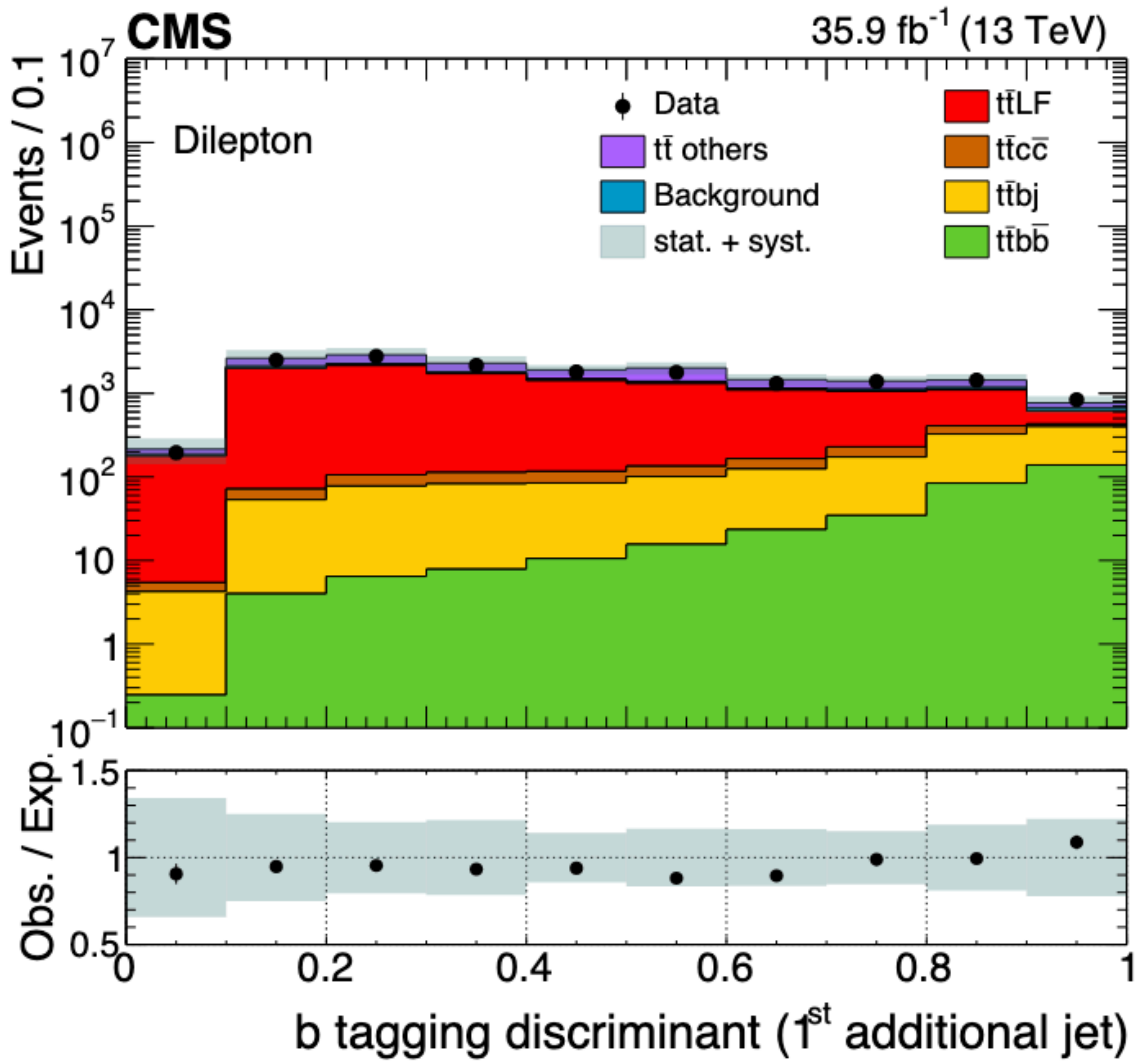

- Theory uncertainties of ~ 20%, cover most of the shape differences between predictions
- Tree-level EW corrections have a minor effect except at high jet multiplicity
- Differences between ATLAS and CMS FxFx setup remain to be understood
- The inclusion of an additional parton in the ME has an effect in all distributions

# Measurement of ttbb

TOP-18-002

- This analysis measures the cross section of ttbb, ttjj and their ratios in the dilepton and lepton+jet channels

| Channel | Jet $p_T$ | Phase space | $t\bar{t}b\bar{b}$ | $t\bar{t}jj$ |
|---|---|---|---|---|
| Dilepton | >30 GeV | VPS | $\ell\ell + \geq 4$ jets (4 b jets) | $\ell\ell + \geq 4$ jets (2 b jets) |
| | | FPS | $t\bar{t} + \geq 2$ b jets (not from $t\bar{t}$) | $t\bar{t} + \geq 2$ jets (not from $t\bar{t}$) |
| Lepton+jets | >20 GeV | VPS | $\ell + \geq 6$ jets (4 b jets) | $\ell + \geq 6$ jets (2 b jets) |
| | | FPS | $t\bar{t} + \geq 2$ b jets (not from $t\bar{t}$) | $t\bar{t} + \geq 2$ jets (not from $t\bar{t}$) |




- Cross-sections extracted from a binned-likelihood fit to the b-tagging discriminator of the additional jets

# Measurement of ttbb

TOP-18-002

- Experimental uncertainties are dominated by b-tagging associated uncertainties.
- Theory uncertainties are dominated by the UE tune uncertainty (Final-state radiation) in the ratio (VPS cross section)

| | $R_{t\bar{t}b\bar{b}/t\bar{t}jj}$ | $\sigma_{t\bar{t}jj}$ [ pb ] | $\sigma_{t\bar{t}b\bar{b}}$ [ pb ] |
|---|---|---|---|
| Dilepton channel (VPS) | | | |
| POWHEG + PYTHIA8 | $0.013 \pm 0.002$ | $2.41 \pm 0.21$ | $0.032 \pm 0.004$ |
| Measurement | $0.017 \pm 0.001 \pm 0.001$ | $2.36 \pm 0.02 \pm 0.20$ | $0.040 \pm 0.002 \pm 0.005$ |
| Dilepton channel (FPS) | | | |
| POWHEG + PYTHIA8 | $0.014 \pm 0.003$ | $163 \pm 21$ | $2.3 \pm 0.4$ |
| MG_aMC@NLO + PYTHIA8 5FS [FxFx] | $0.015 \pm 0.003$ | $159 \pm 25$ | $2.4 \pm 0.4$ |
| POWHEG + HERWIG++ | $0.011 \pm 0.002$ | $170 \pm 25$ | $1.9 \pm 0.3$ |
| Measurement | $0.018 \pm 0.001 \pm 0.002$ | $159 \pm 1 \pm 15$ | $2.9 \pm 0.1 \pm 0.5$ |
| Lepton+jets channel (VPS) | | | |
| POWHEG + PYTHIA8 | $0.017 \pm 0.002$ | $30.5 \pm 3.0$ | $0.52 \pm 0.06$ |
| Measurement | $0.020 \pm 0.001 \pm 0.001$ | $31.0 \pm 0.2 \pm 2.9$ | $0.62 \pm 0.03 \pm 0.07$ |
| Lepton+jets channel (FPS) | | | |
| POWHEG + PYTHIA8 | $0.013 \pm 0.002$ | $290 \pm 29$ | $3.9 \pm 0.4$ |
| MG_aMC@NLO + PYTHIA8 5FS [FxFx] | $0.014 \pm 0.003$ | $280 \pm 40$ | $4.1 \pm 0.4$ |
| POWHEG + HERWIG++ | $0.011 \pm 0.002$ | $321 \pm 36$ | $3.4 \pm 0.5$ |
| Measurement | $0.016 \pm 0.001 \pm 0.001$ | $292 \pm 1 \pm 29$ | $4.7 \pm 0.2 \pm 0.6$ |

ttbb analysis from ATLAS with same conclusions

- **Predictions systematically lower than measurements for ttbb**

# Progresses in ttbb modelling

ATL-PHYS-PUB-2022-026

LHCHWG-2022-003

- Process with two different scales playing a role ($m_t$ and $p_T^{jet}$, play a role)
- In early Run-2 measurements: Powheg+Pythia8 inclusive tt simulation with extra b-jets were coming from the shower.

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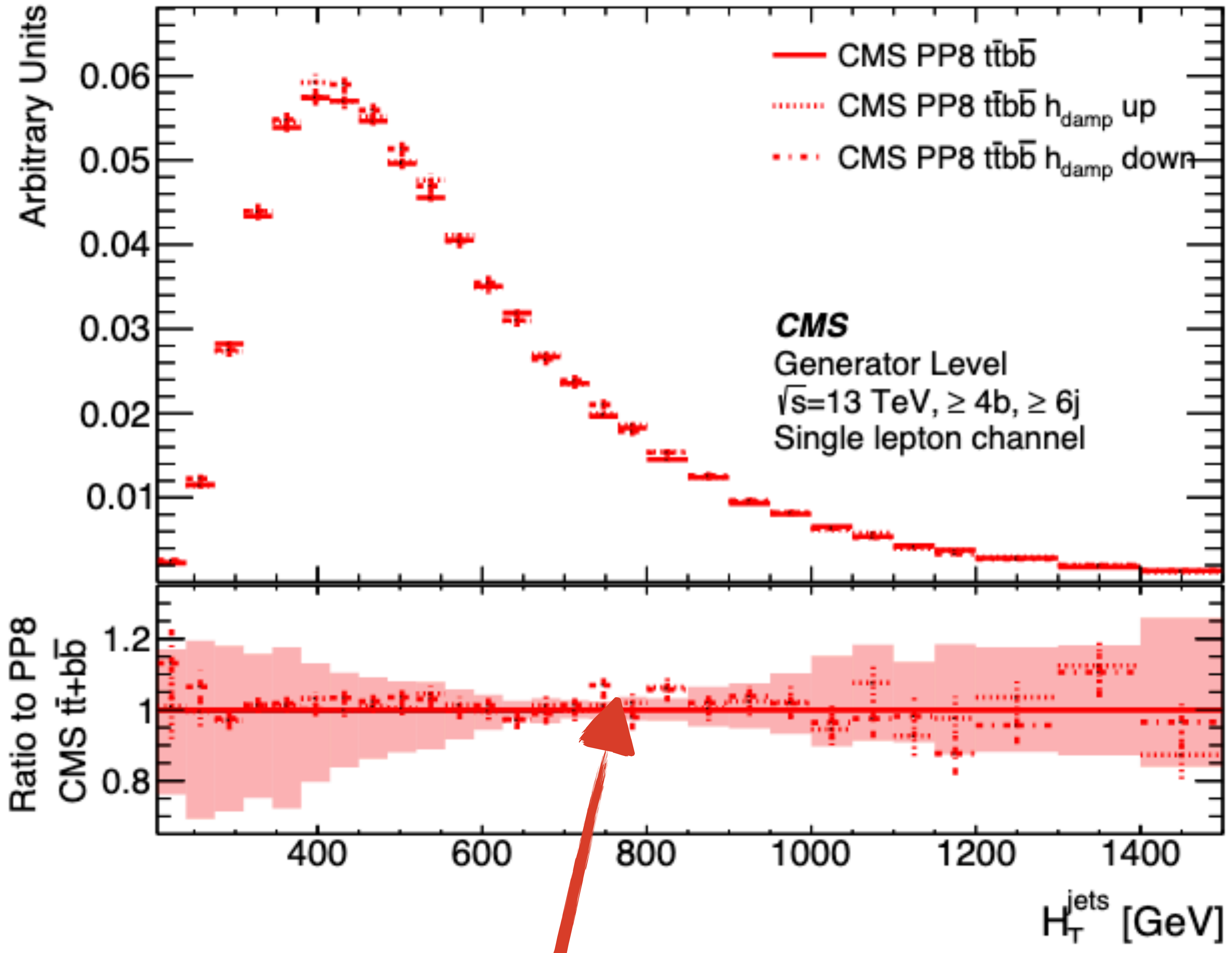
- In ttbb early Run-2 measurements: Powheg+Pythia8 inclusive tt simulation with extra b-jets were coming from the shower.
- For full Run-2 ttH measurements: move to ttbb with Powheg+Pythia8 in the 4FS
  - Studies of the variations of the matching prescription, parton shower and generator settings

| | name | ME | Generator | ME order | Shower | Tune[a] | NNPDF PDF set (ME) | $h_{damp}$ | $h_{bzd}$ | $\sigma^{\geq 1lep}$ [pb] |
|---|---|---|---|---|---|---|---|---|---|---|
| ATLAS | PP8 $t\bar{t}b\bar{b}$ | $t\bar{t}b\bar{b}$ | $t\bar{t}b\bar{b}$-Powheg | NLO | Pythia 8.224 | A14 | 4FS 3.0 NLO as 0118 | $H_T/2$ | 5 | 18.72 |
| CMS | PP8 $t\bar{t}b\bar{b}$ | $t\bar{t}b\bar{b}$ | $t\bar{t}b\bar{b}$-Powheg | NLO | Pythia 8.230 | CP5 | 4FS 3.1 NLO as 0118 | $1.379 \cdot m_t$ | 2 | 23.86 |
| ATLAS | PP8 $t\bar{t}b\bar{b}$ $h_{bzd}$ 2 | $t\bar{t}b\bar{b}$ | $t\bar{t}b\bar{b}$-Powheg | NLO | Pythia 8.224 | A14 | 4FS 3.0 NLO as 0118 | $H_T/2$ | 2 | 18.46 |
| ATLAS | PP8 $t\bar{t}b\bar{b}$ dipole | $t\bar{t}b\bar{b}$ | $t\bar{t}b\bar{b}$-Powheg | NLO | Pythia 8.224 | A14, dipoleRecoil[b] | 4FS 3.0 NLO as 0118 | $H_T/2$ | 2 | 18.72 |
| ATLAS | PH7 $t\bar{t}b\bar{b}$ | $t\bar{t}b\bar{b}$ | $t\bar{t}b\bar{b}$-Powheg | NLO | Herwig 7.1.6 | default | 4FS 3.0 NLO as 0118 | $H_T/2$ | 5 | 18.47 |
| ATLAS | Sherpa $t\bar{t}b\bar{b}$ | $t\bar{t}b\bar{b}$ | Sherpa 2.2.10 | NLO | Sherpa | default | 4FS 3.0 NNLO as 0118 | — | — | 20.24 |
| CMS | PP8 $t\bar{t}b\bar{b}$ $h_{damp}$ up | $t\bar{t}b\bar{b}$ | $t\bar{t}b\bar{b}$-Powheg | NLO | Pythia 8.230 | CP5 | 4FS 3.1 NLO as 0118 | $2.305 \cdot m_t$ | 5 | 23.86 |
| CMS | PP8 $t\bar{t}b\bar{b}$ $h_{damp}$ down | $t\bar{t}b\bar{b}$ | $t\bar{t}b\bar{b}$-Powheg | NLO | Pythia 8.230 | CP5 | 4FS 3.1 NLO as 0118 | $0.8738 \cdot m_t$ | 5 | 23.86 |
| ATLAS | PP8 $t\bar{t}$ | $t\bar{t}$ | Powheg v2 | NLO | Pythia 8.210 | A14 | 5FS 3.0 NLO | $1.5 \cdot m_t$ | 5 | 451.78[c] |
| CMS | PP8 $t\bar{t}$ | $t\bar{t}$ | Powheg v2 | NLO | Pythia 8.230 | CP5 | 5FS 3.1 NLO | $1.5 \cdot m_t$ | 5 | 451.78[c] |
| ATLAS | PH7 $t\bar{t}$ | $t\bar{t}$ | Powheg v2 | NLO | Herwig 7.13 | default | 5FS 3.0 NLO | $1.5 \cdot m_t$ | 5 | 451.78[c] |
| ATLAS | aMC+P8 $t\bar{t}$ | $t\bar{t}$ | MG5_aMC@NLO | NLO | Pythia 8.210 | A14 | 5FS 3.0 NLO | — | — | 451.78[c] |
| CMS | PP8 $t\bar{t}$ $h_{damp}$ up | $t\bar{t}$ | Powheg v2 | NLO | Pythia 8.230 | CP5 | 5FS 3.1 NLO | $2.305 \cdot m_t$ | 5 | 451.78[c] |
| CMS | PP8 $t\bar{t}$ $h_{damp}$ down | $t\bar{t}$ | Powheg v2 | NLO | Pythia 8.230 | CP5 | 5FS 3.1 NLO | $0.8738 \cdot m_t$ | 5 | 451.78[c] |

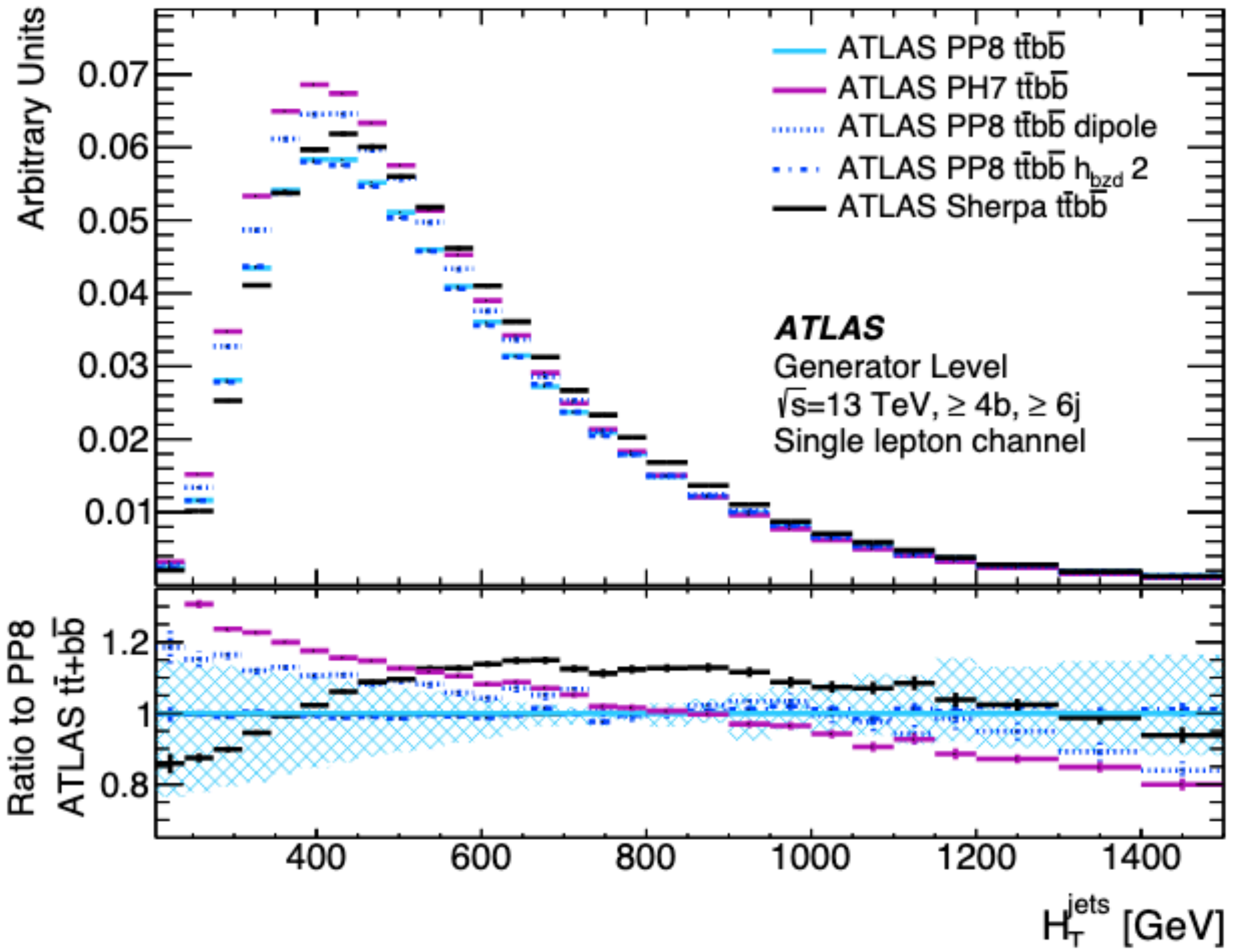
# Progresses in ttbb modelling

ATL-PHYS-PUB-2022-026

LHCHWG-2022-003




Variations shown in the legend will be used by each collaboration to asses an uncertainty

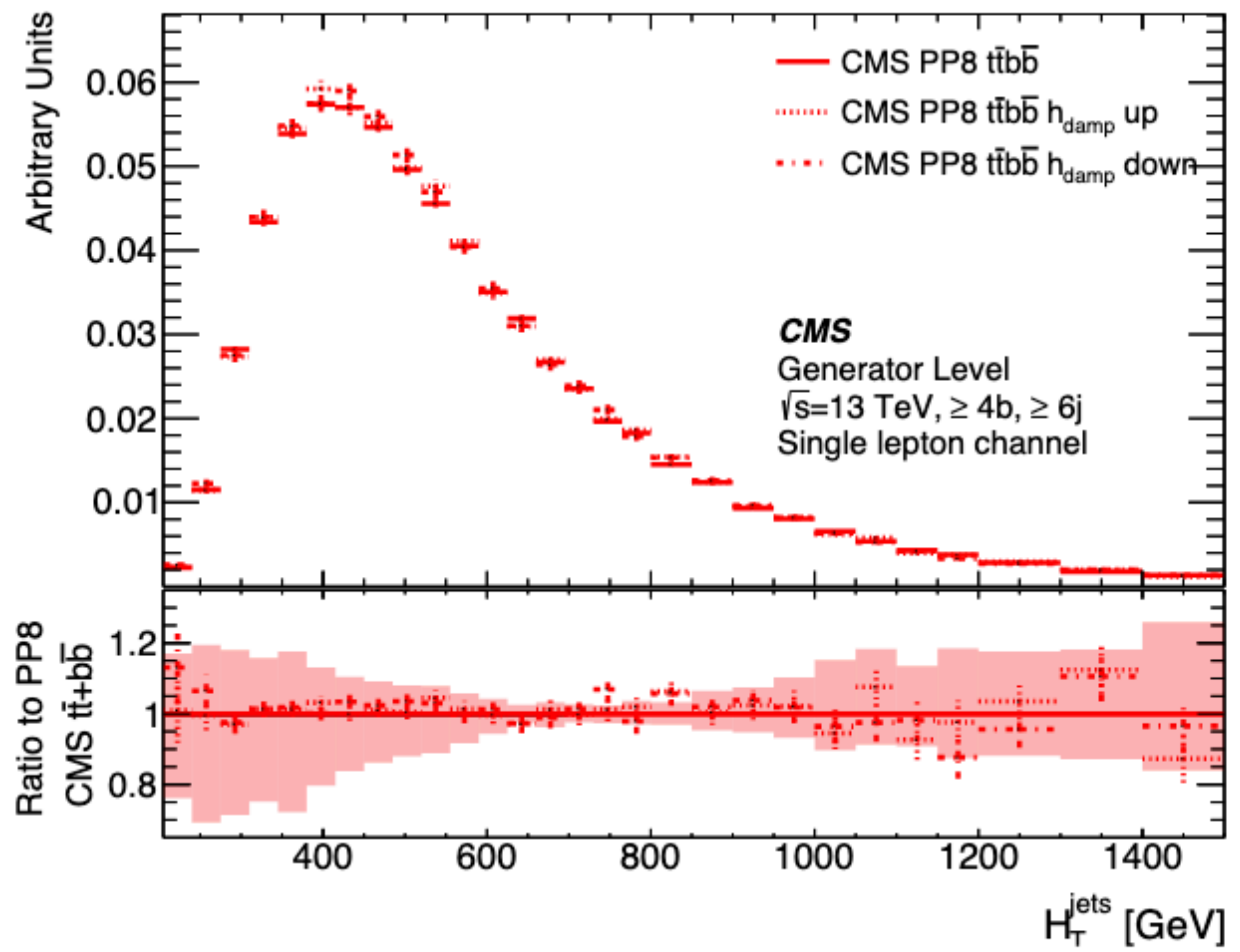



- $h_{damp}$ variations (regulates the high-pT emission against which the tt system recoils) in CMS

# Progresses in ttbb modelling

[ATL-PHYS-PUB-2022-026](#)

[LHCHWG-2022-003](#)

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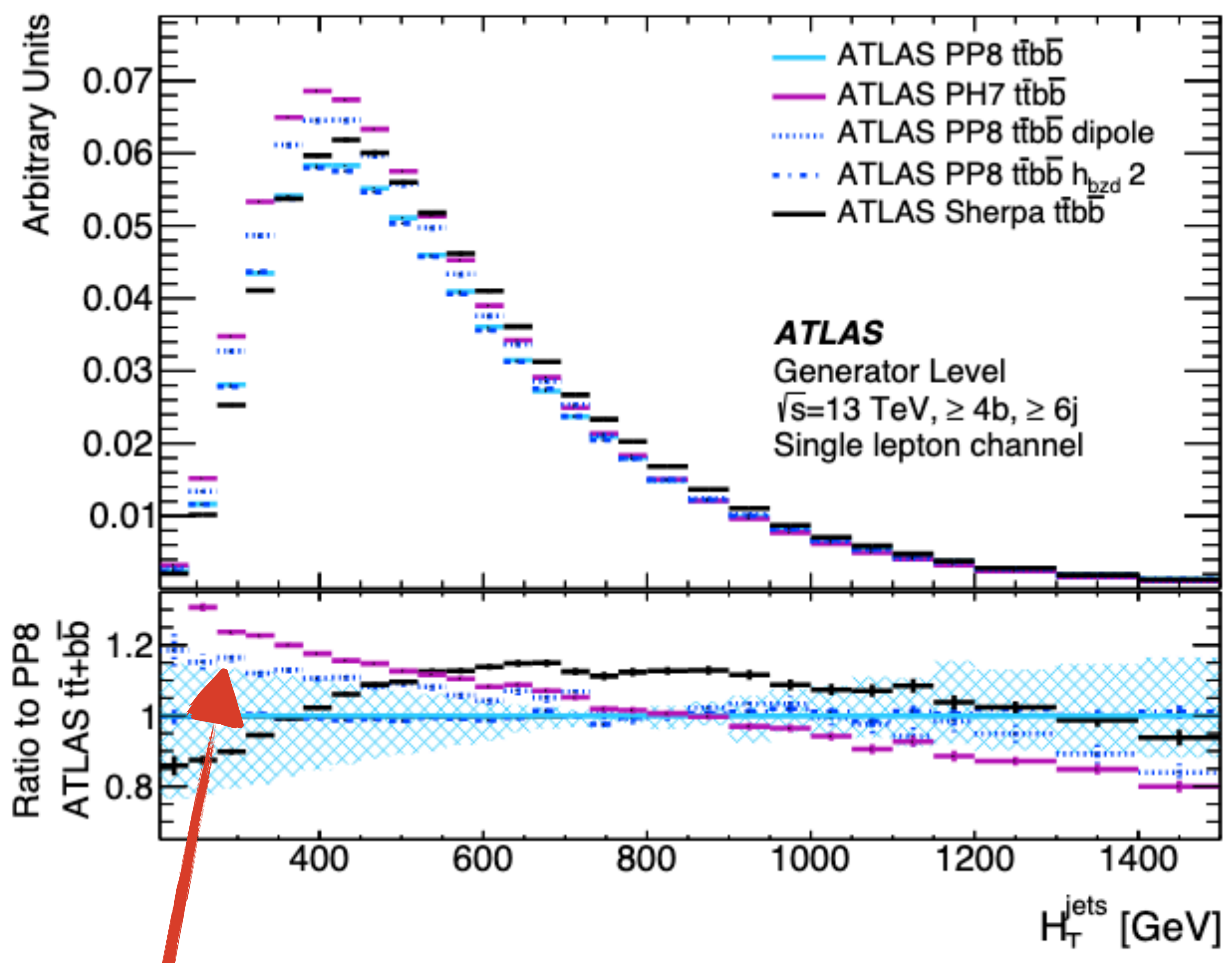
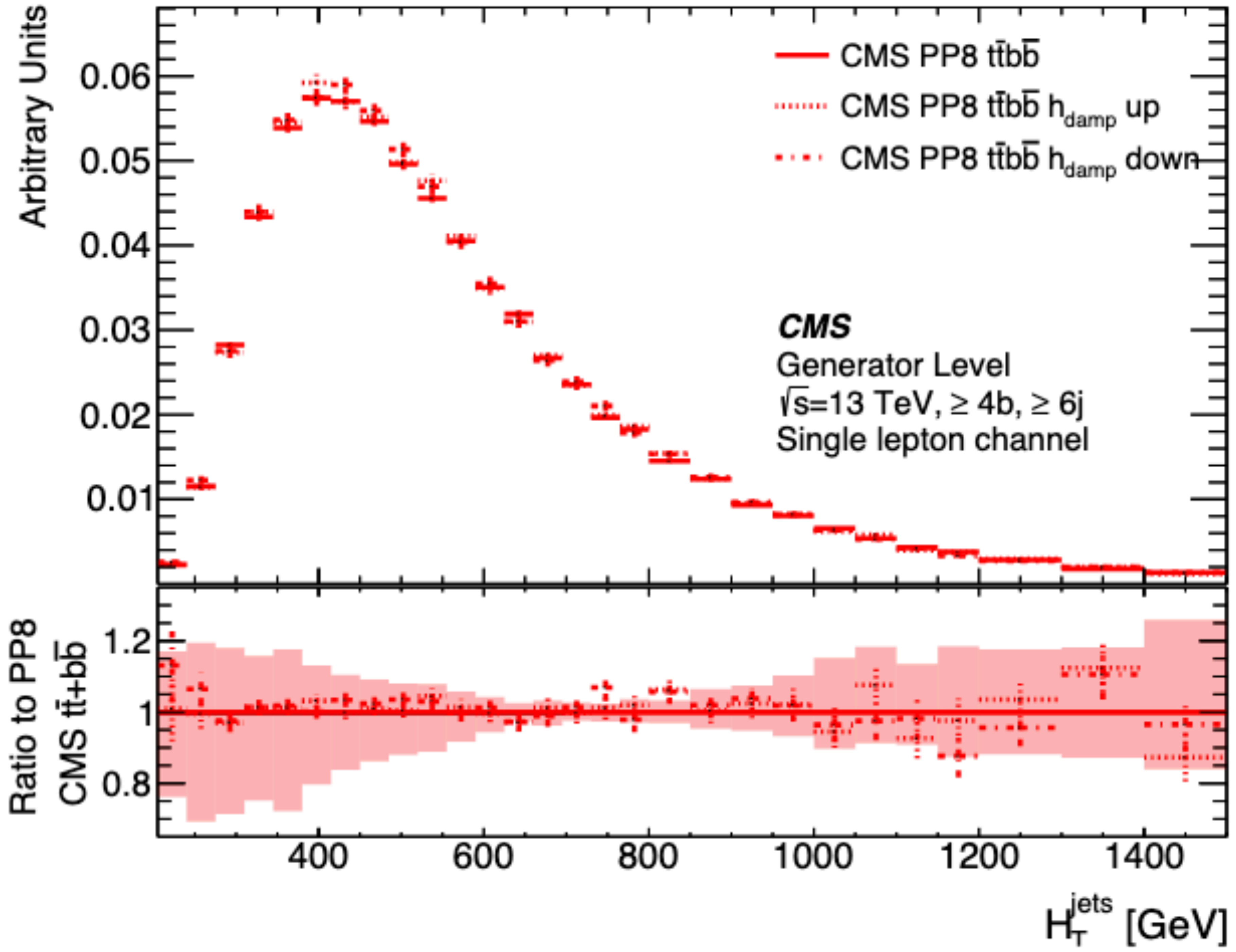



- $h_{damp}$ variations (regulates the high-pT emission against which the tt system recoils) in CMS
- $h_{bzd}$ variations (regulates splitting between finite and singular part of real emission) in ATLAS

# Progresses in ttbb modelling

ATL-PHYS-PUB-2022-026

LHCHWG-2022-003

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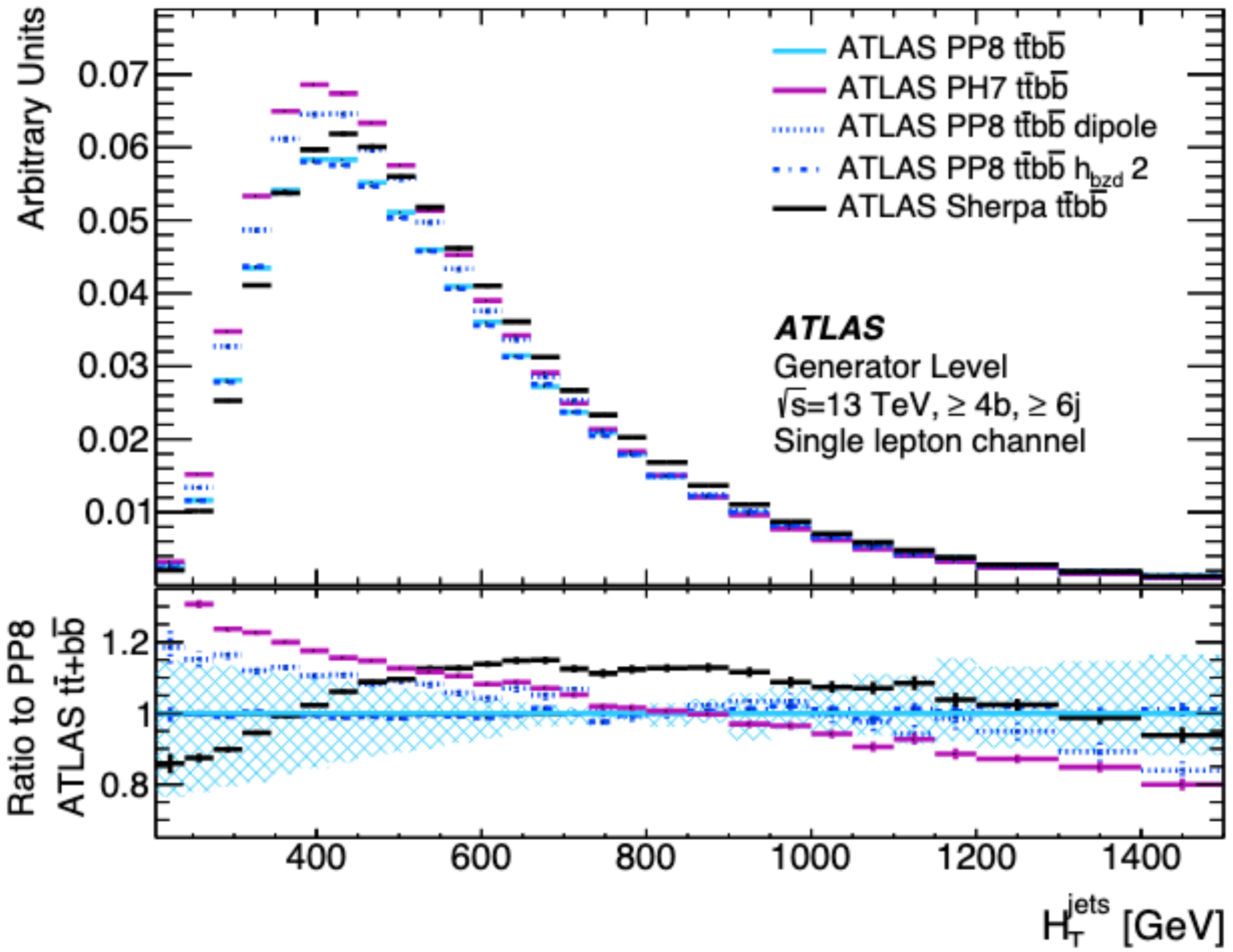


- $h_{damp}$ variations (regulates the high-pT emission against which the tt system recoils) in CMS
- $h_{bzd}$ variations (regulates splitting between finite and singular part of real emission) in ATLAS
- Variations wrt other generators exceeds scale uncertainties
- Good agreement of baseline Powheg+Pythia8 setup between experiments

# SIGNAL MODELLING IN THE PRESENCE OF BSM EFFECTS

# Introduction: Progresses in signal modelling with BSM effects

- In the lack of evidence of BSM signals in direct searches at the LHC, SMEFT has become a powerful tool to systematically analyse datasets assuming that new physics happens at not accesible scales

$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \sum_i \frac{c_i^{d=6}}{\Lambda^2}\mathcal{O}^{d=6} + \sum_i \frac{c_i^{d=8}}{\Lambda^4}\mathcal{O}^{d=8} + \ldots$$

- Keeps same symmetries and particle content as SM
- Constrain EFT coefficients ⇒ Constrain different classes of UV theories

- In ATLAS, the methodology followed for Higgs interpretations was established in this note

**See Giacinto's talk for the state-of-the-art of these interpretations**

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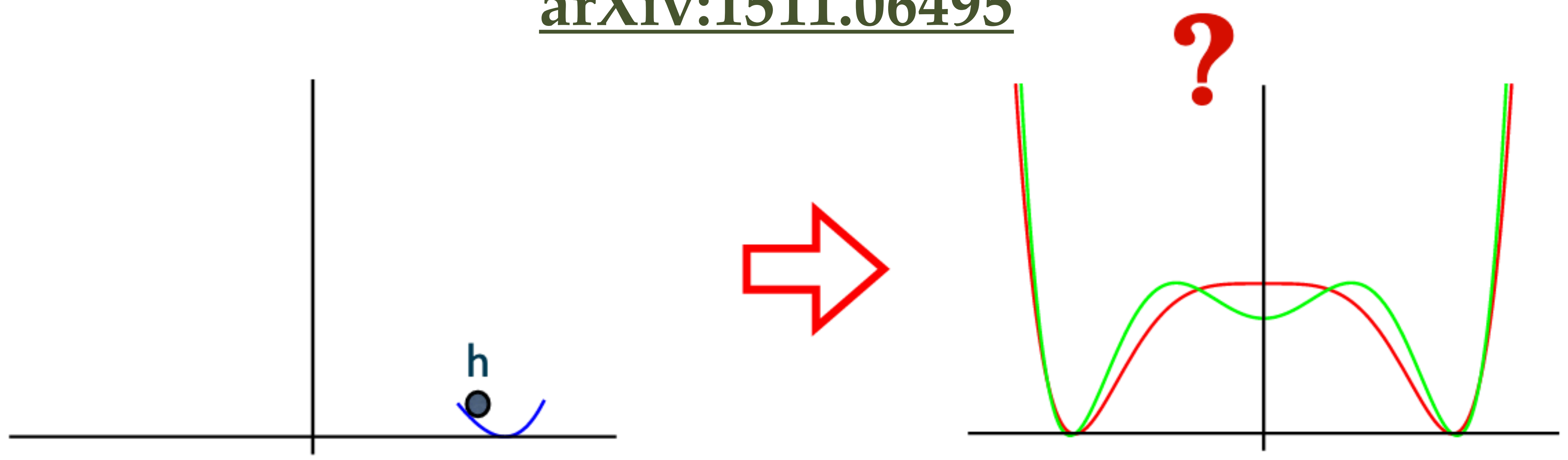
arXiv:1511.06495




- Higgs trilinear self coupling appearing at NLO EW
  - Not included standard EFT interpretations
  - Dedicated $\kappa_\lambda$ parametrisation
- Weakly constrained by measurements, help to understand better the Higgs potential

$$V(H) = \frac{1}{2}m_H^2 H^2 + \lambda_3 v H^3 + \frac{\lambda_4}{4}H^4$$

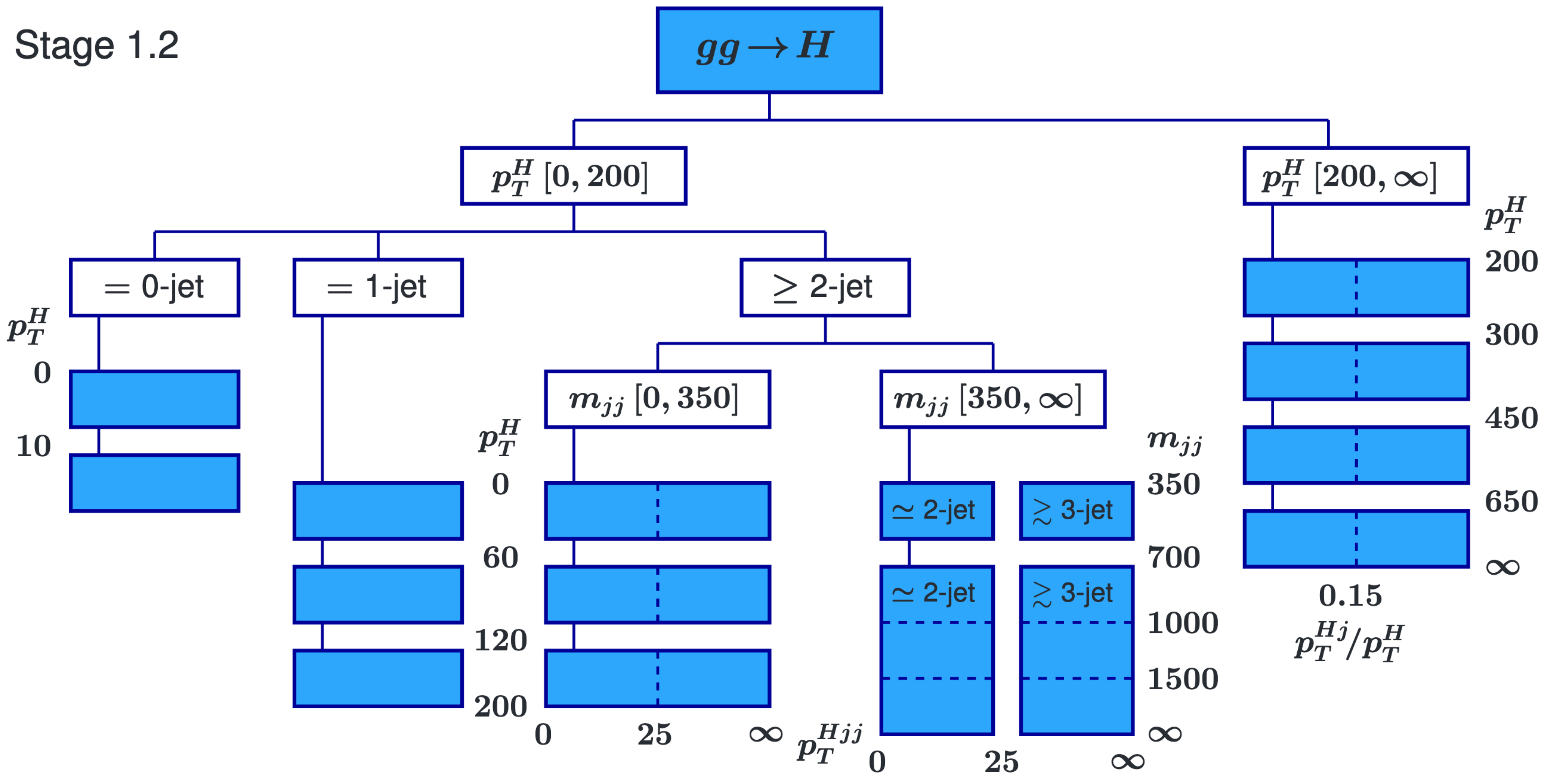
In SM:

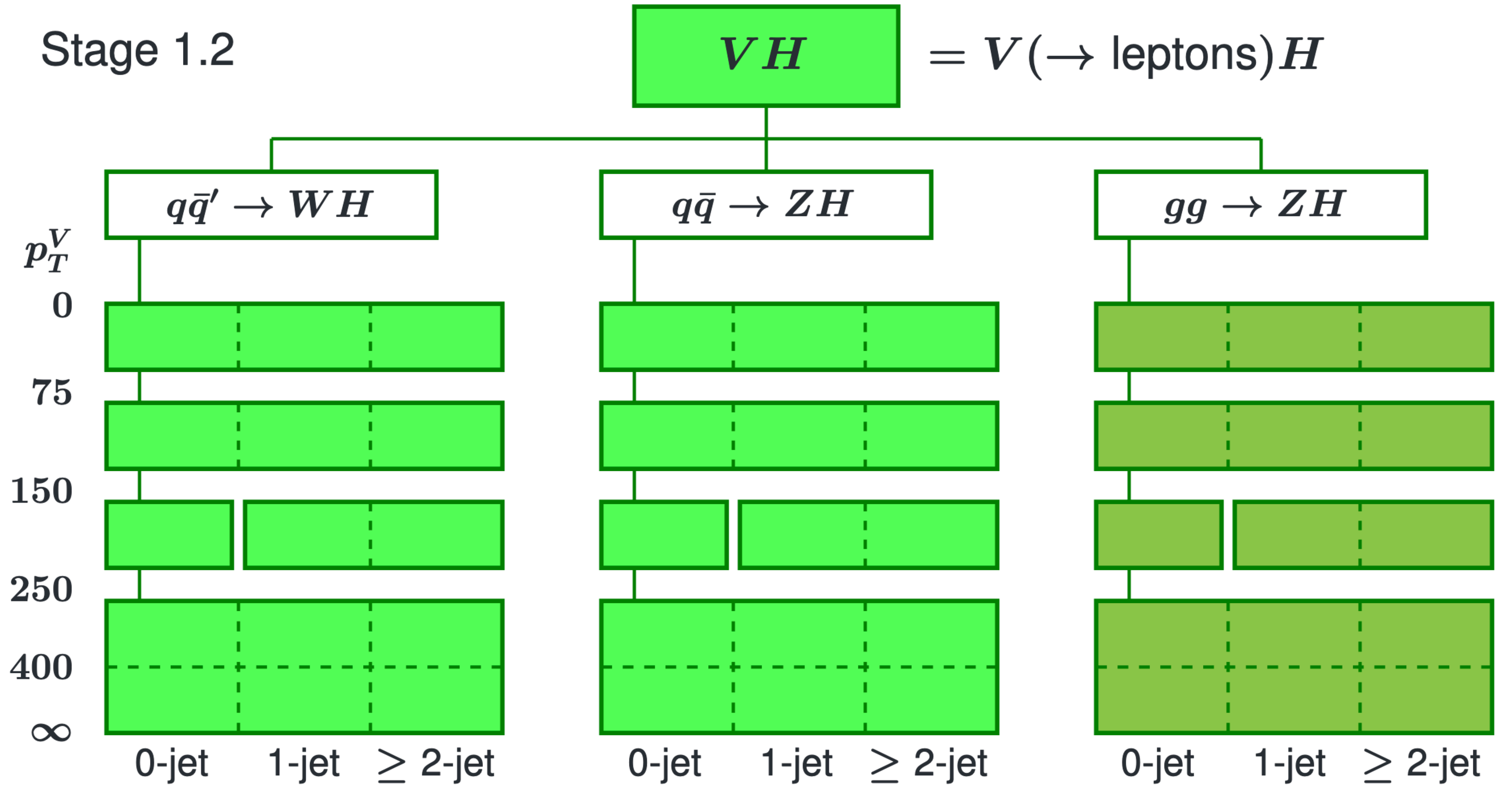
$$\lambda_3 = \lambda_4 = \lambda_{SM} = \frac{m_H^2}{2v^2}$$

# Higgs signals in the presence of SMEFT

ATL-PHYS-PUB-2019-042

- STXS is a natural framework to include the reparametrisation of the signal strengths in terms of EFT coefficients
  - Large number of bins measured in latests publications in the different production modes
  - Bins defined at high mass/momentum with enhanced EFT effects



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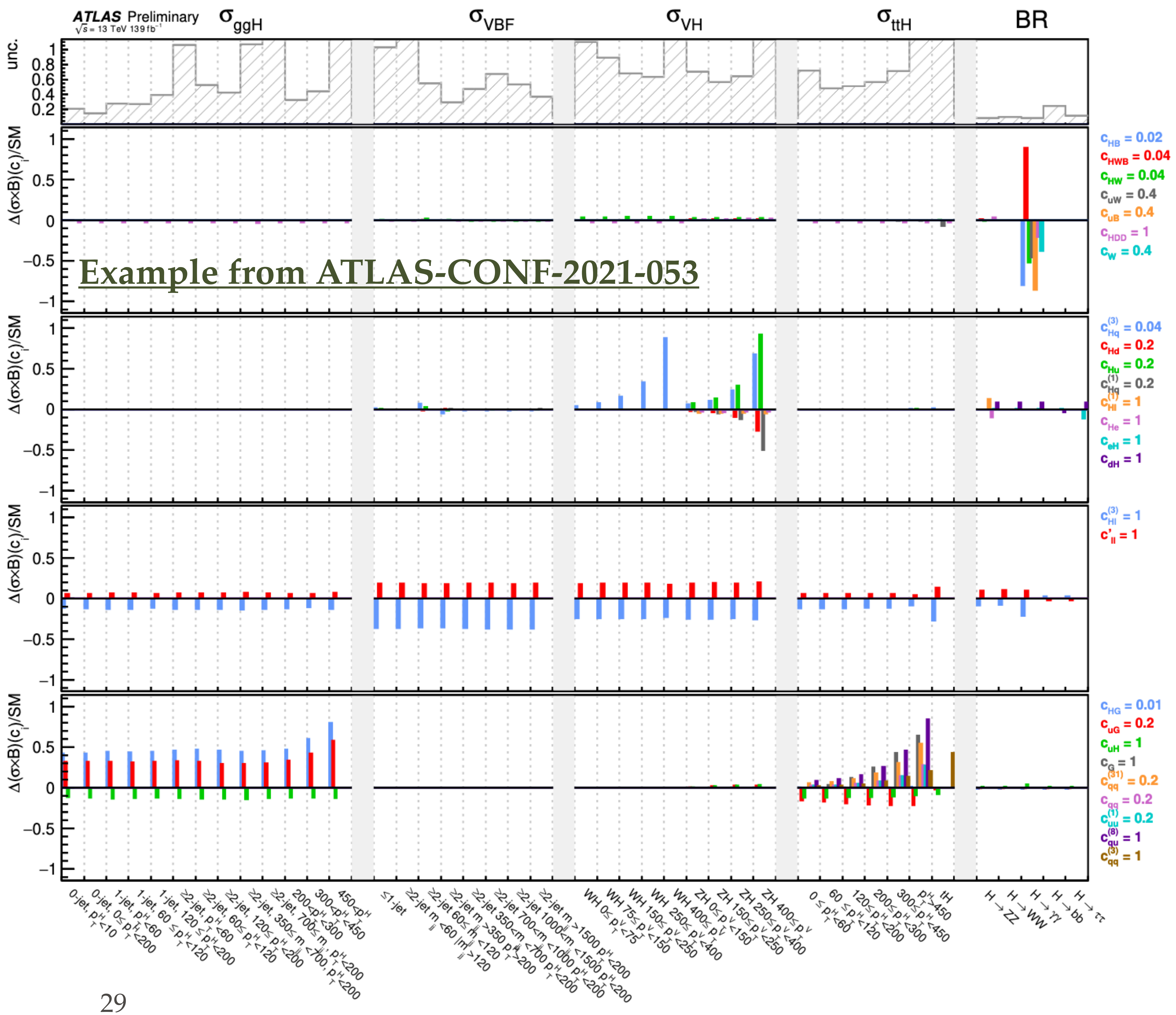
$$(\sigma\times B)^{i,H\to X} = (\sigma\times B)^{i,H\to X}_{\mathrm{SM,(N(N))NLO}}\left(1+\frac{\sigma^i_{\mathrm{int,(N)LO}}}{\sigma^i_{\mathrm{SM,(N)LO}}}+\frac{\sigma^i_{\mathrm{BSM,(N)LO}}}{\sigma^i_{\mathrm{SM,(N)LO}}}\right)\left(\frac{1+\frac{\Gamma^{H\to X}_{\mathrm{int}}}{\Gamma^{H\to X}_{\mathrm{SM}}}+\frac{\Gamma^{H\to X}_{\mathrm{BSM}}}{\Gamma^{H\to X}_{\mathrm{SM}}}}{1+\frac{\Gamma^{H}_{\mathrm{int}}}{\Gamma^{H}_{\mathrm{SM}}}+\frac{\Gamma^{H}_{\mathrm{BSM}}}{\Gamma^{H}_{\mathrm{SM}}}}\right)$$

SMEFT simulation of d=6 effects using SMEFTsim, SMEFTatNLO in the mW input scheme interfaced with MadGraph or analytical calculations for loop decays



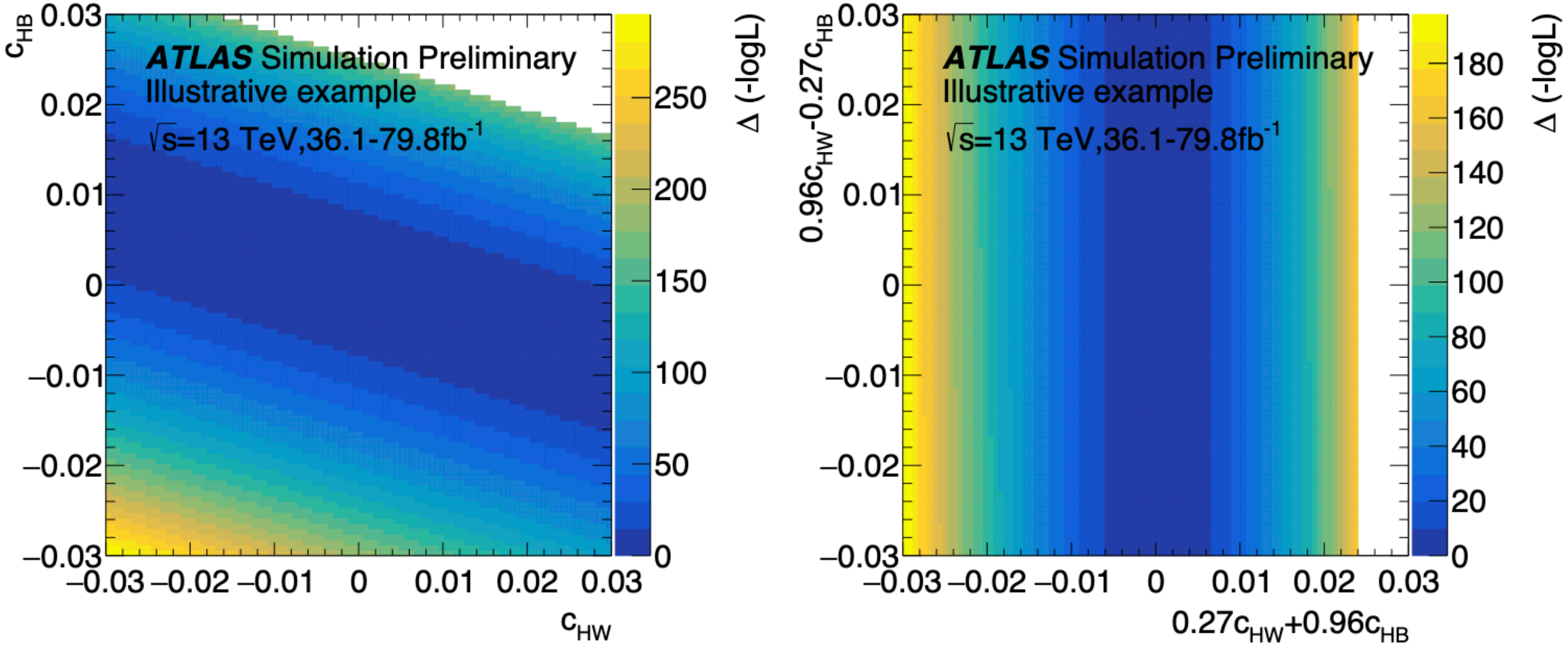
# Higgs signals in the presence of SMEFT

ATL-PHYS-PUB-2019-042

- Higgs analyses do not have enough power to constraint the whole EFT space
  - Recent analyses moving from U(3)5 symmetry scheme to topU3l or top (in light of global EFT fits)
  - Dimensionality reduction with a PCA starting from the Fisher information matrix of the measurement

e.g. ATLAS-CONF-2021-053 went from 31 WC in the Warsaw basis to 13 fitted directions

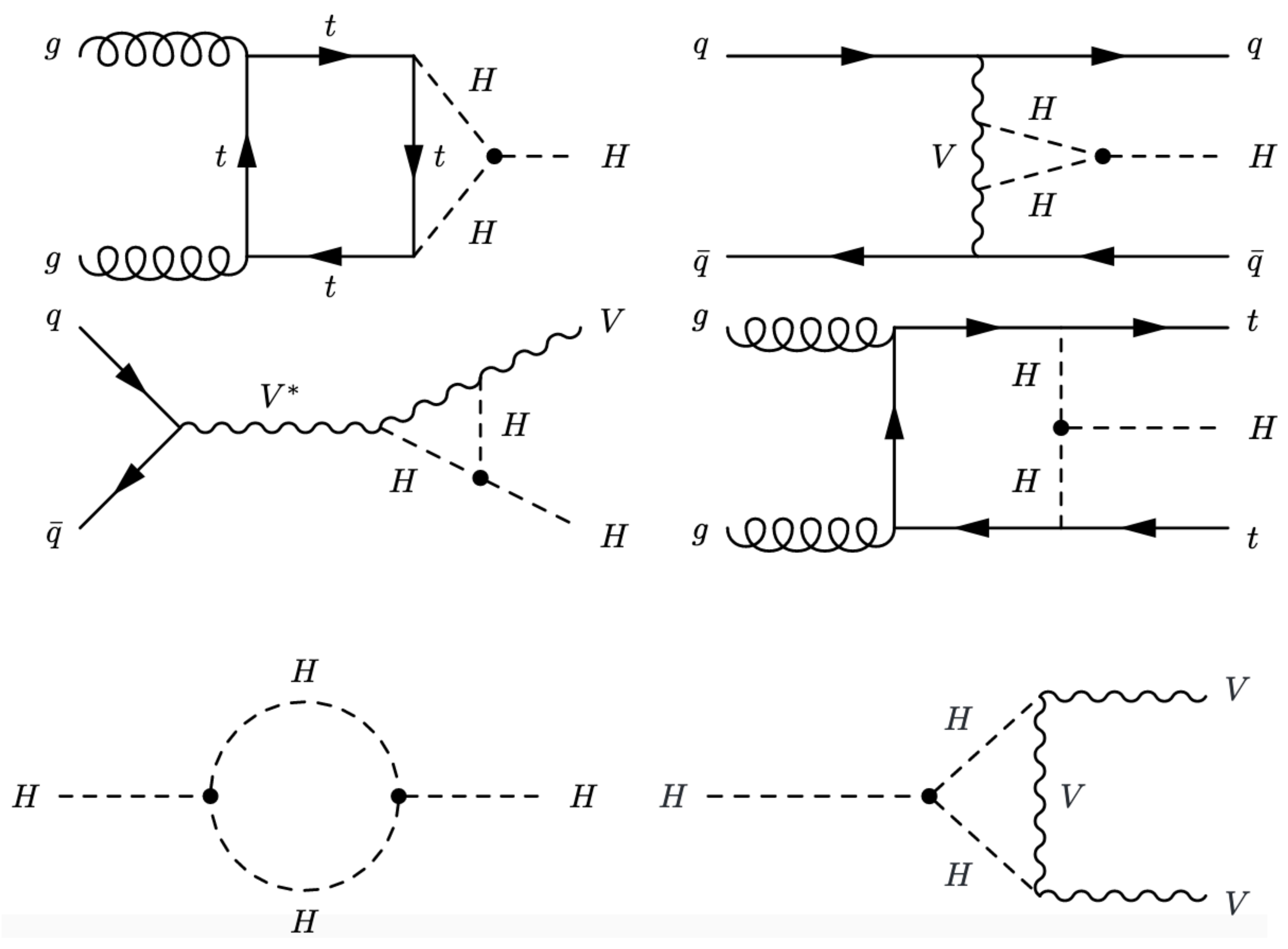
Ilustrative example with only two parameters




- Still many challenges ahead for the understanding the associated uncertainties: in the generation, the truncation of the EFT expansion, the validity of the EFT itself, how to treat the backgrounds…
  - Since mid-2020 under the umbrella of the LHC EFT WG

# Higgs signals with anomalous $\lambda$

[LHCHWG-2022-002]




Diagrams sensitive to the Higgs trilinear self coupling

- An anomalous $\kappa_\lambda$ can affect the differential H production cross sections
  - The effect is larger for VH and ttH production
  - pTH is sensitive specially in the low region
  - Double Higgs production also affected (not covered)

$\kappa_V$ or $\kappa_F$ depending on the production mode

C1i gives the magnitude of the $\kappa\lambda$ correction

$$\frac{\sigma^i_{NLO_{EW}}}{\sigma^i_{NLO_{EW},SM}} = Z_H^{BSM}\left[\frac{(\kappa_\lambda - 1)C_1^i}{K^i_{EW}} + \kappa_i^2\right]$$

Higgs wave function renormalisation ($\propto \kappa_\lambda^2$)

$K^i_{EW}$ k-factor for the full set of EW corrections

- $\kappa_\lambda$-corrections do not factorise from other EW corrections
  - Should be treated consistently in the above formula and the analysis

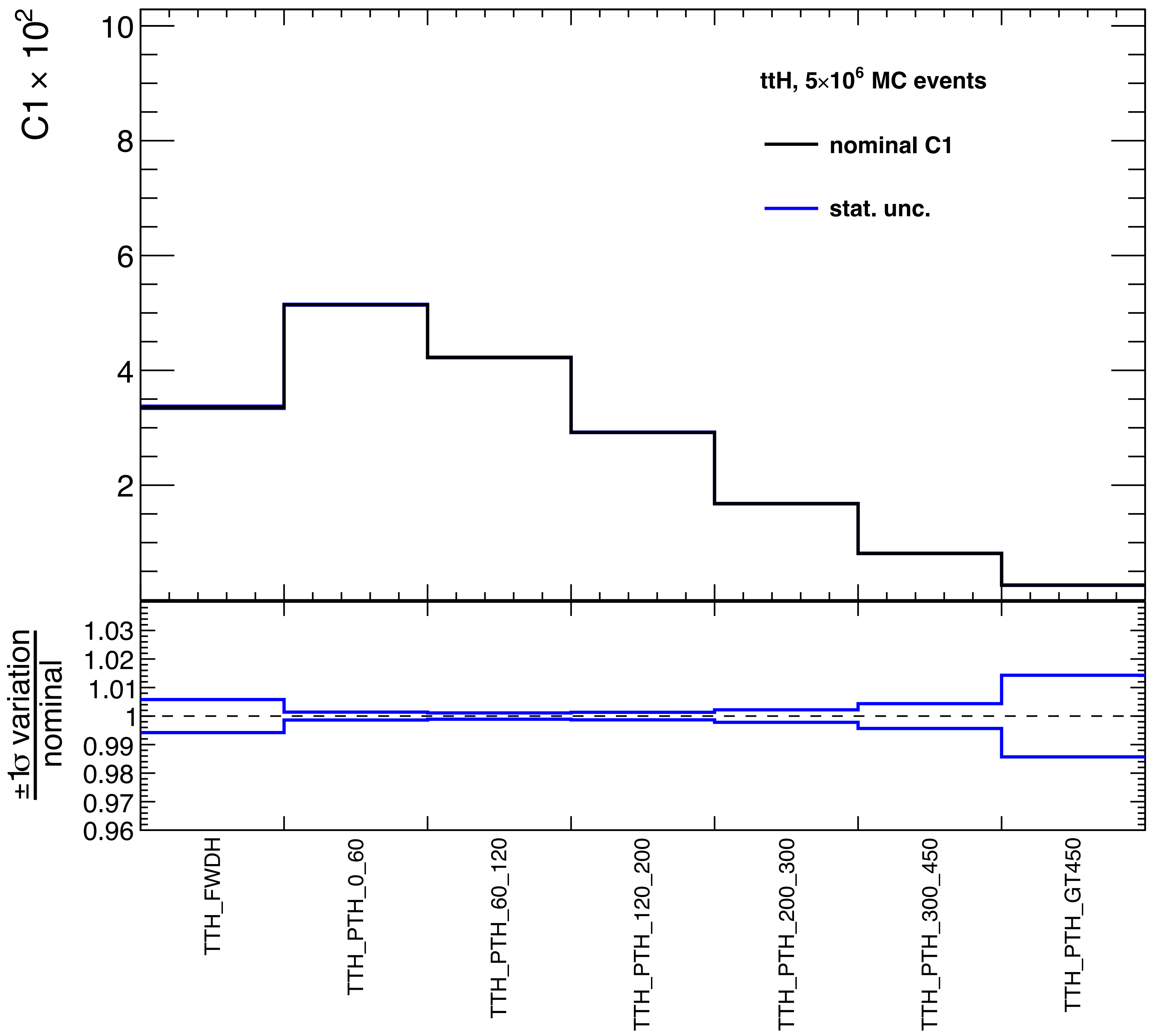
See talk from Alessandro Tabarini about CMS interpretation in HZZ

# Higgs signals with anomalous $\lambda$

LHCHWG-2022-002

- Calculations of C1 using MG5_aMC@NLO with the HiggsSelfCoupling UFO model
  - Each production mode is computed at LO
  - The model also compute the corrections for the NLO EW $\kappa_\lambda$ effects.

$$C_1^i = \frac{\sum_j w^j_{NLO}}{\sum_j w^j_{LO}}$$




- $K_{EW}$ also provided per STXS bins computed with MG5_aMC@NLO for ttH or HAWK for other production modes
- The inputs of this note will allow to constrain $\lambda$ with ATLAS and CMS STXS measurements

**Example of common parametrisation between theorists and experiments**
**⇒ Model to other efforts**

# Summary

- **The sensitivity of ttH-ML and ttH(->bb) analyses are limited by the modelling of the ttW and ttbb backgrounds**
  - Precision measurements are needed to test new pQCD predictions, which currently show some tension with the measurements.
  - Efforts from the theory community to provide more accurate calculations and from the experiments to incorporate them in the measurements
  - Need for an agreement in the estimation of the the modelling uncertainties between ATLAS and CMS
- **Signal modelling in the presence of BSM effects allows to use single Higgs data to search for deviations from the SM**
  - Tendency to provide common parametrisation between experiments

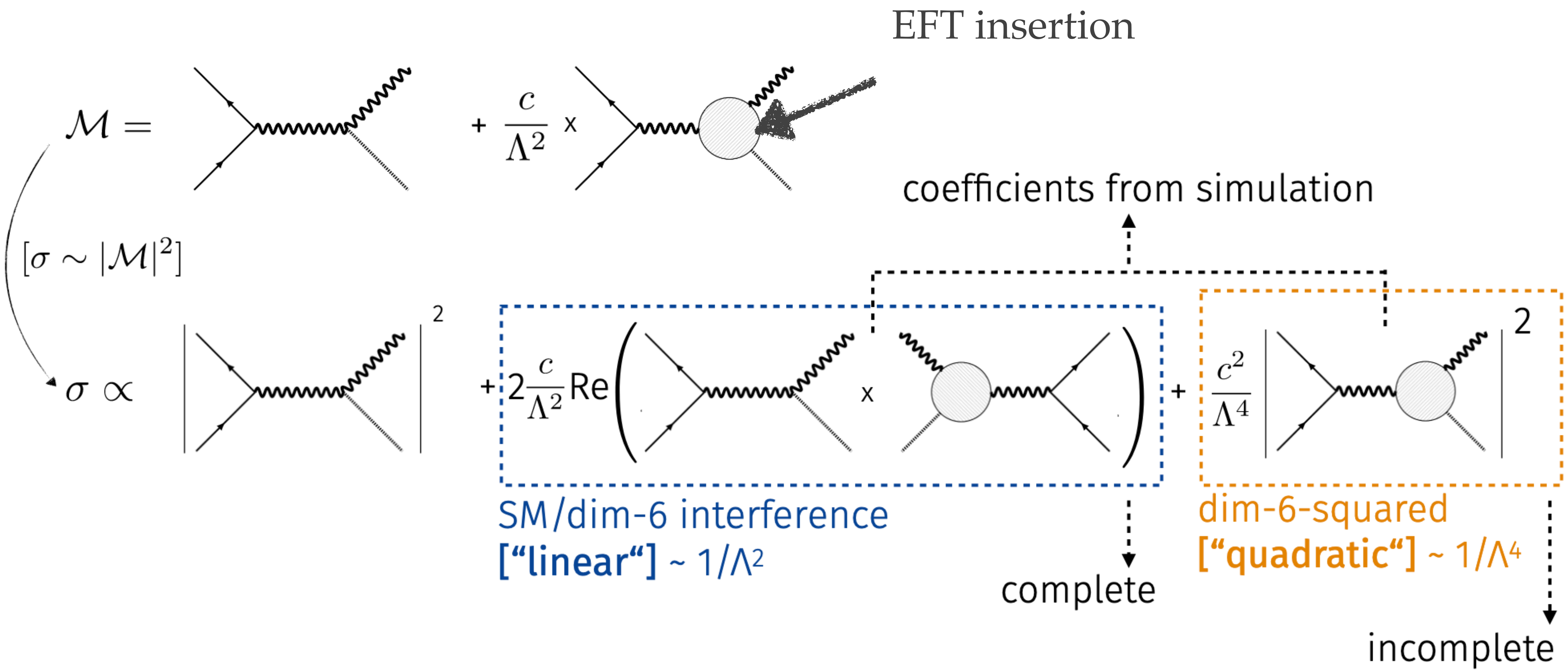
# Thanks!

# BACK-UP

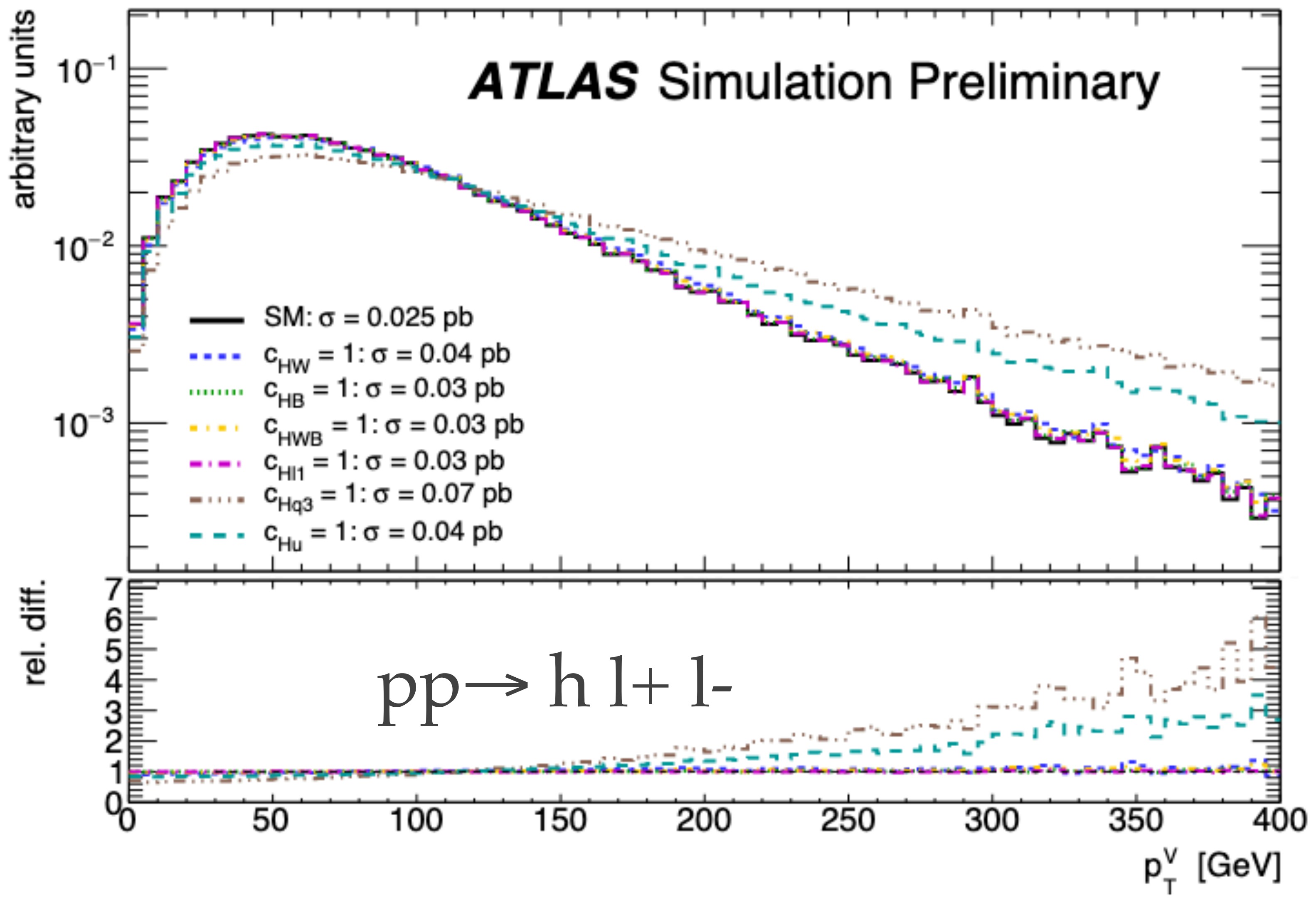
# Higgs signals in the presence of SMEFT

ATL-PHYS-PUB-2019-042

- Most of Higgs interpretations in the SMEFT based on reparametrisation of the signal strengths / cross sections in the likelihood in terms of the EFT coefficients



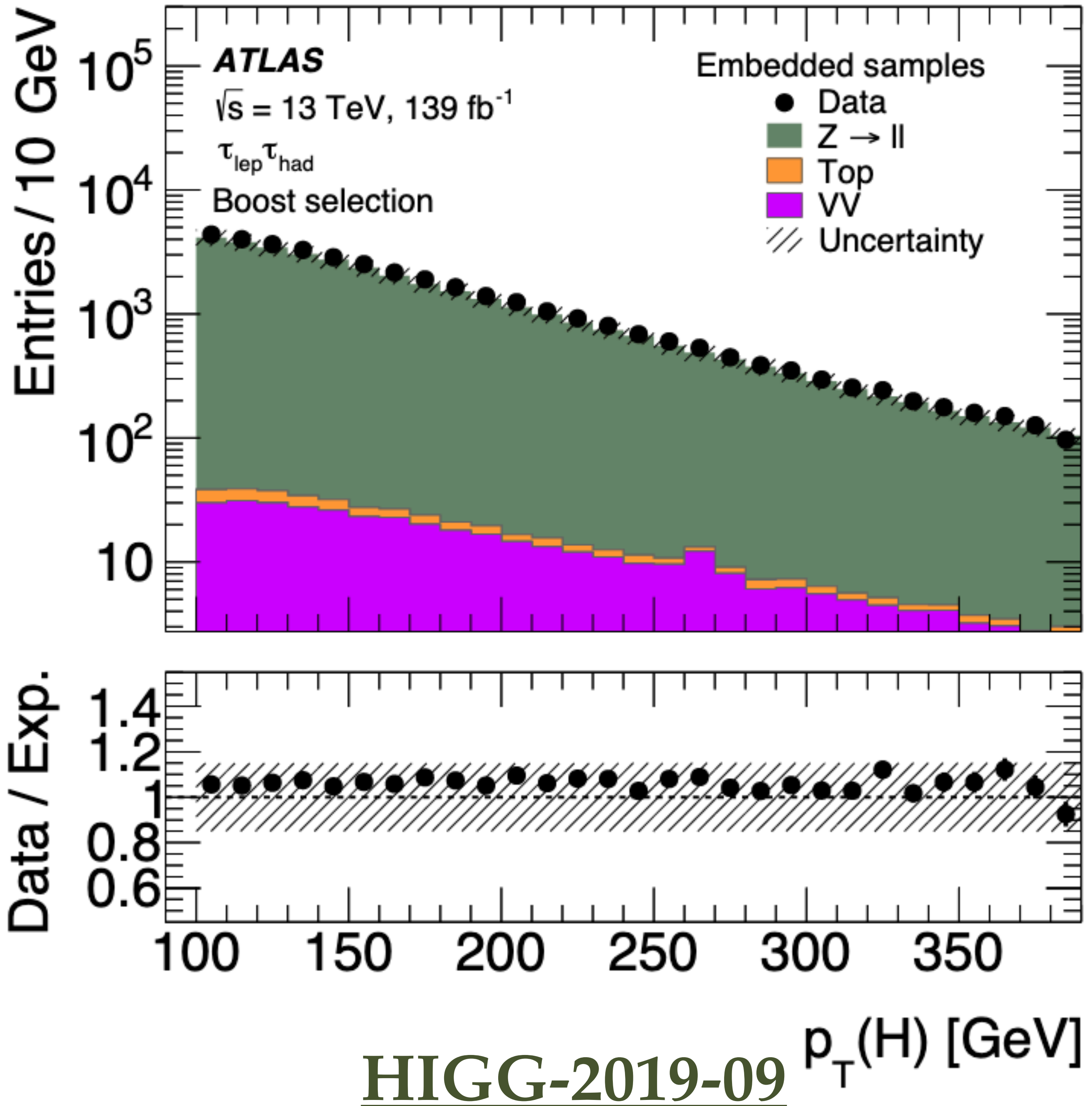

- Simulation of EFT signal with MG5_aMC at lowest order
  - SMEFTsim UFO model
  - SMEFTatNLO incorporated for loop induced processes
  - Analytic calculation of NLO QED for H→γγ decays



# BACKGROUNDS TO H→ $\tau\tau$

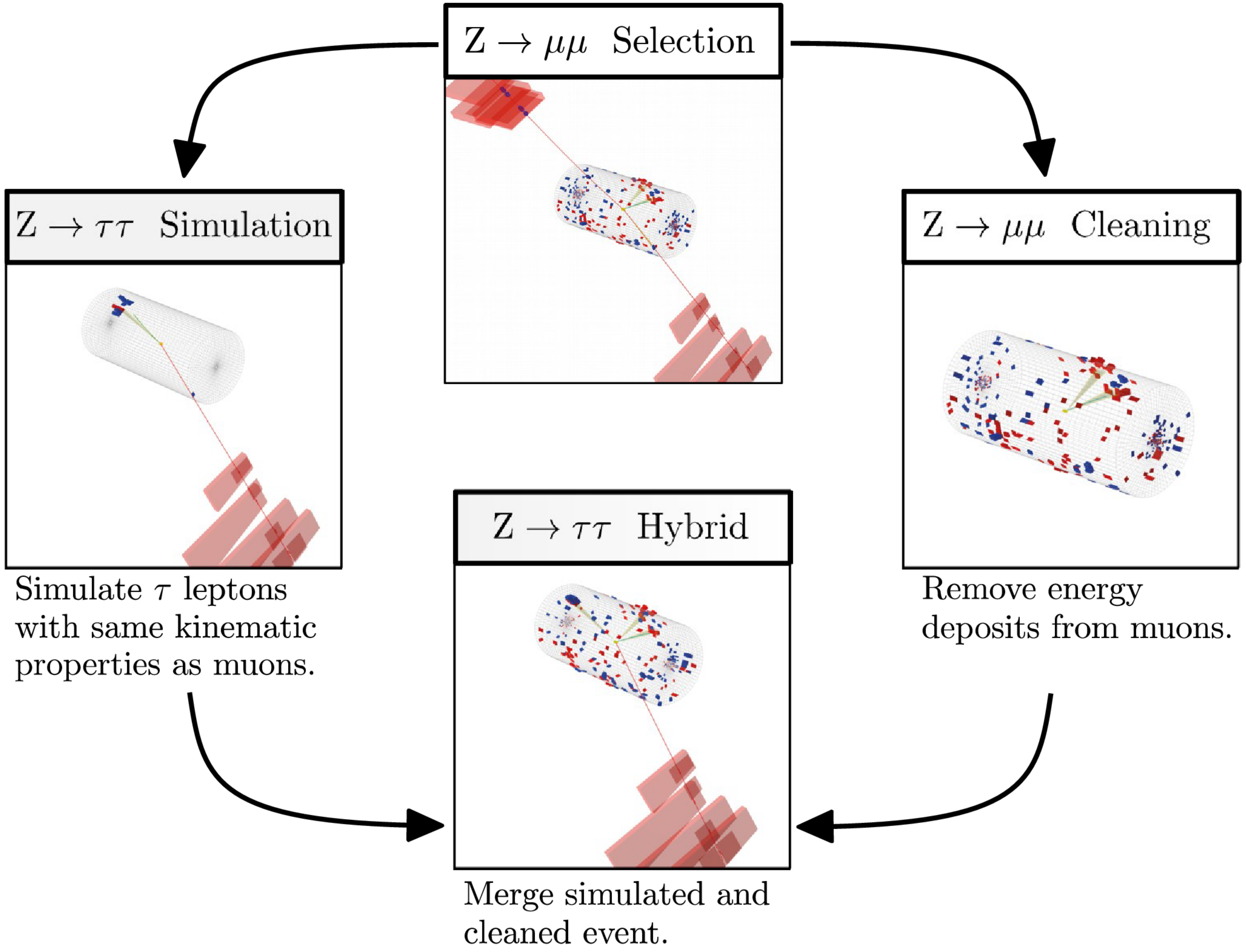
# Introduction: backgrounds to H→ $\tau\tau$

- $Z(\rightarrow \tau\tau)$+jets is the dominant background in H→ $\tau\tau$
- No statistically significant study of this background can be performed in data without looking at the signal regions
  - Usage of embedding




HIGG-2019-09

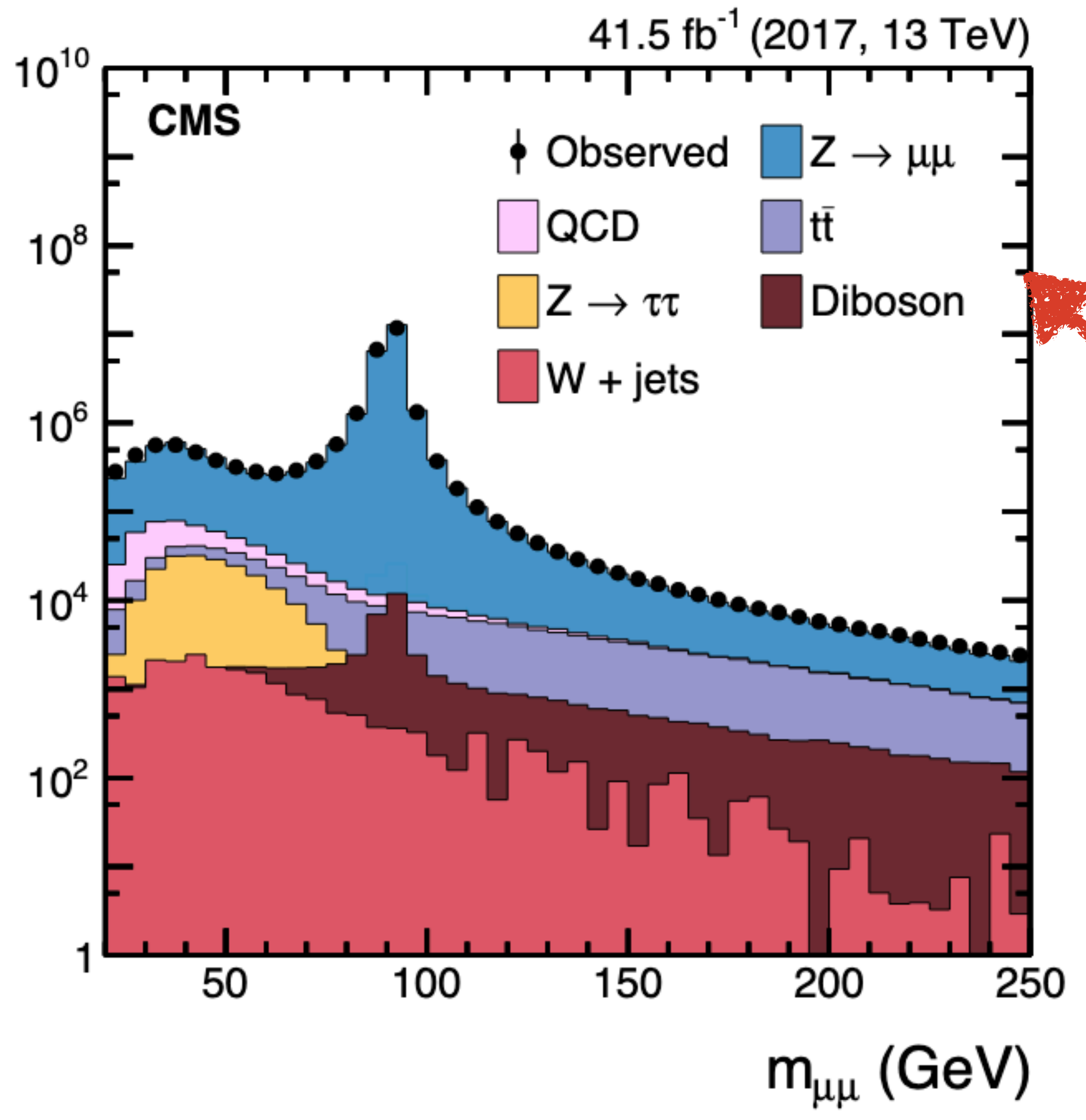
Idea: estimate $\tau\tau$ backgrounds from data with minimal simulation input



# The embedding technique

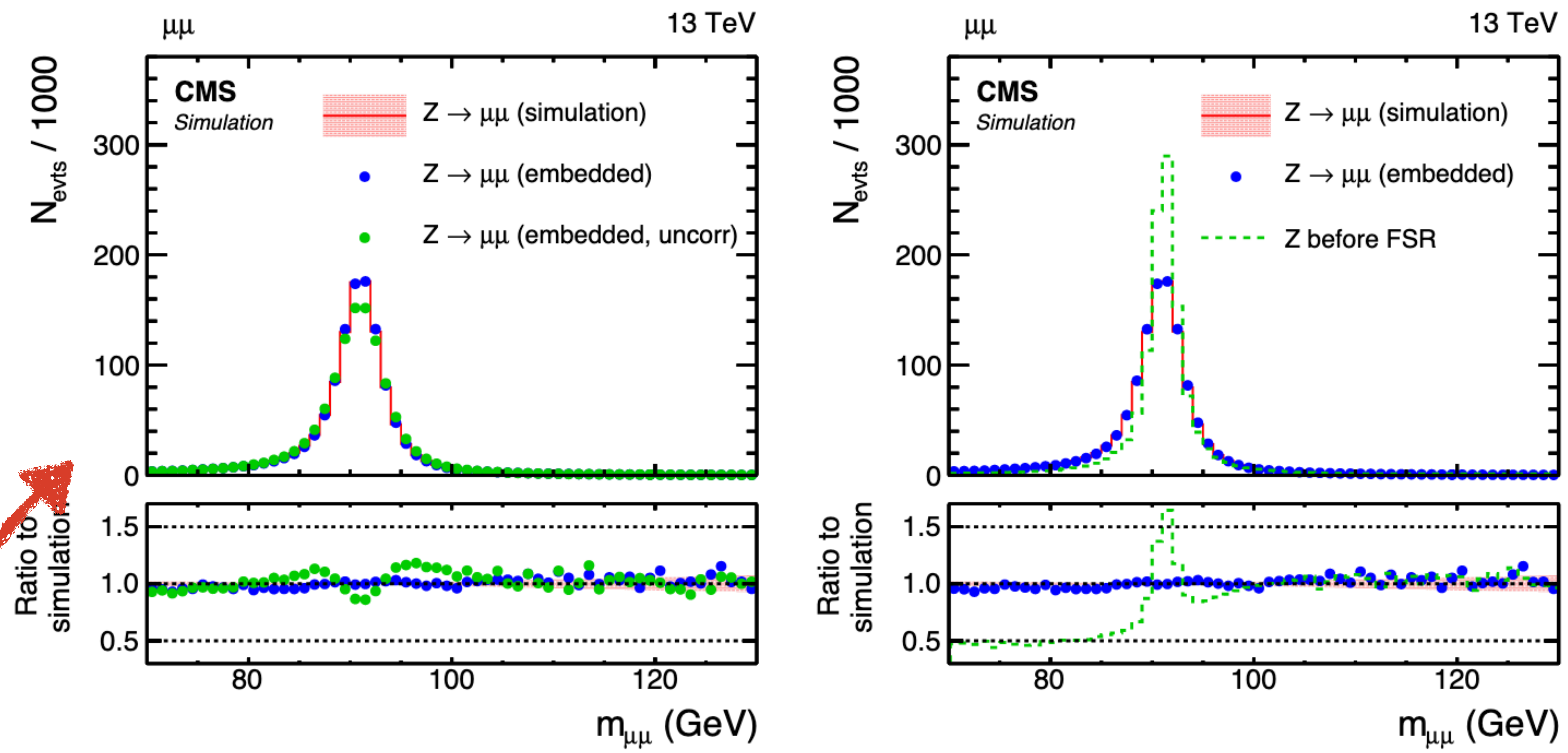
TAU-18-001

- Avoids the challenges of describing the UE or production of associated jets well in simulation
  - Tau lepton decays relies on simulation which is well understood




Composition of the selected μμ events as a function of $m_{\mu\mu}$

Effect of corrections for detector response and FSR in $m_{\mu\mu}$

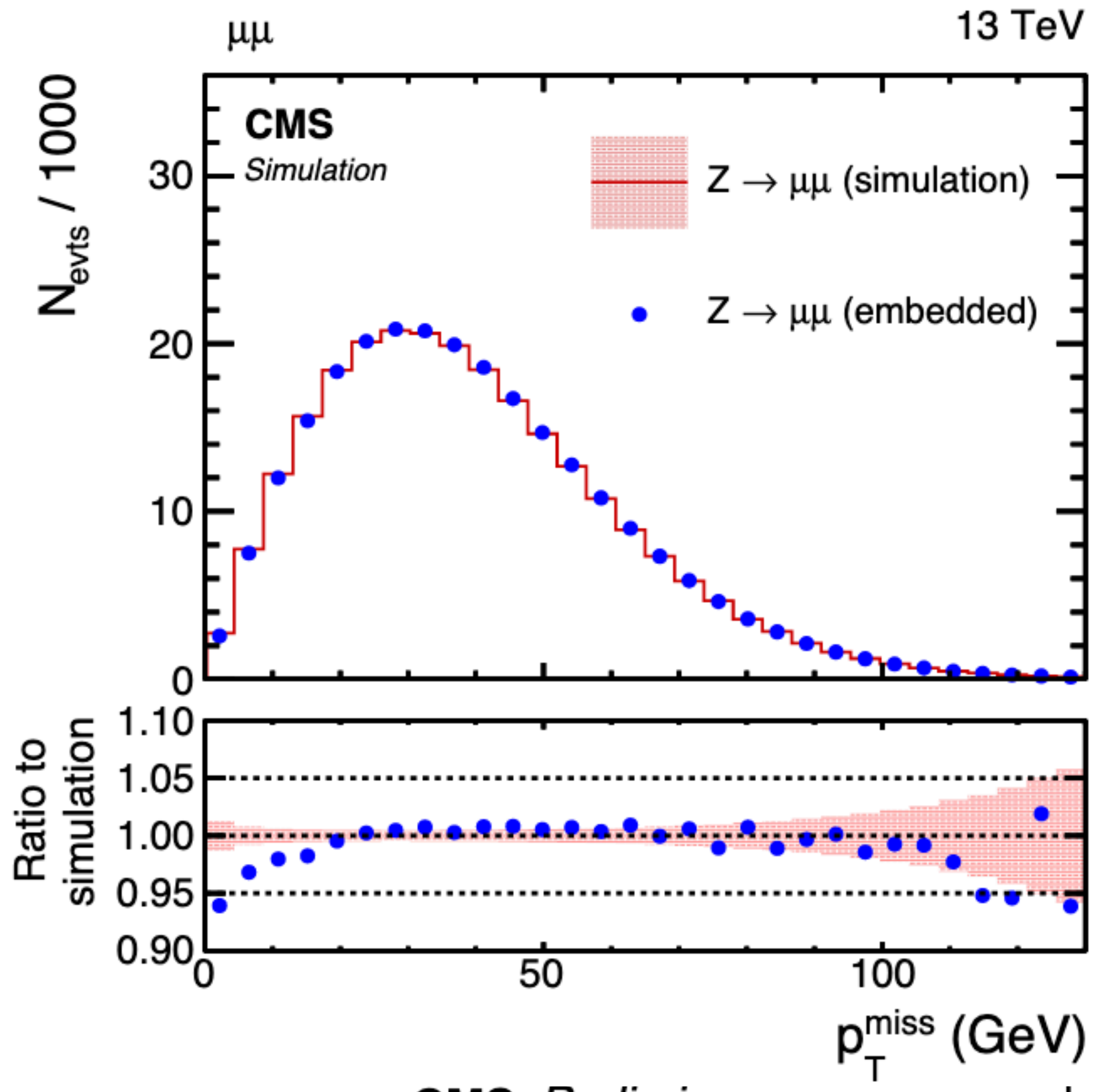


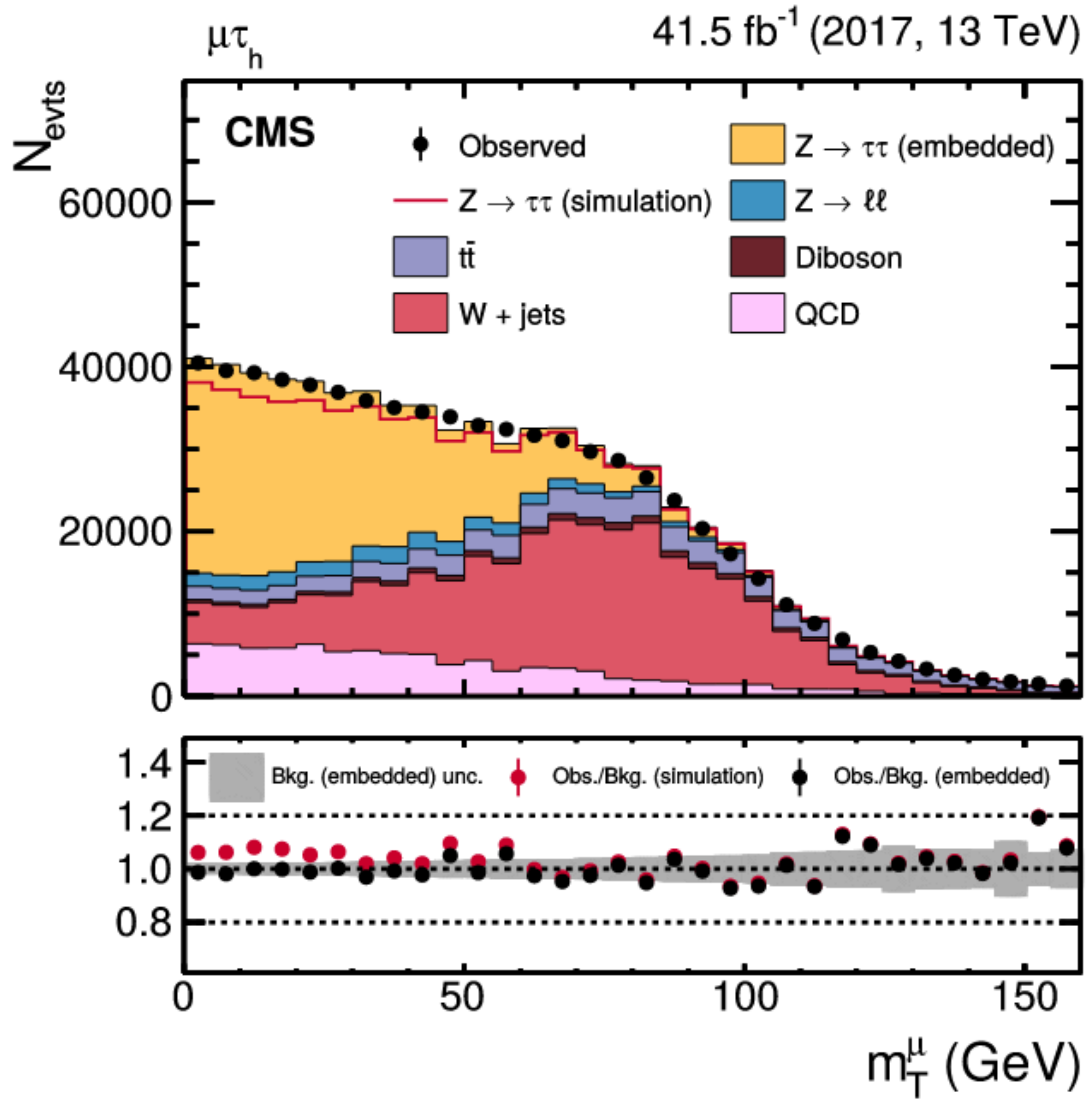

- Corrections and selections applied: 4-momenta to account for the mass difference between μ and $\tau$, kinematic filtering to the tau decay products, $m_{\mu\mu}$-dependent scaling to broad resolution due to finite detector response, FSR corrections

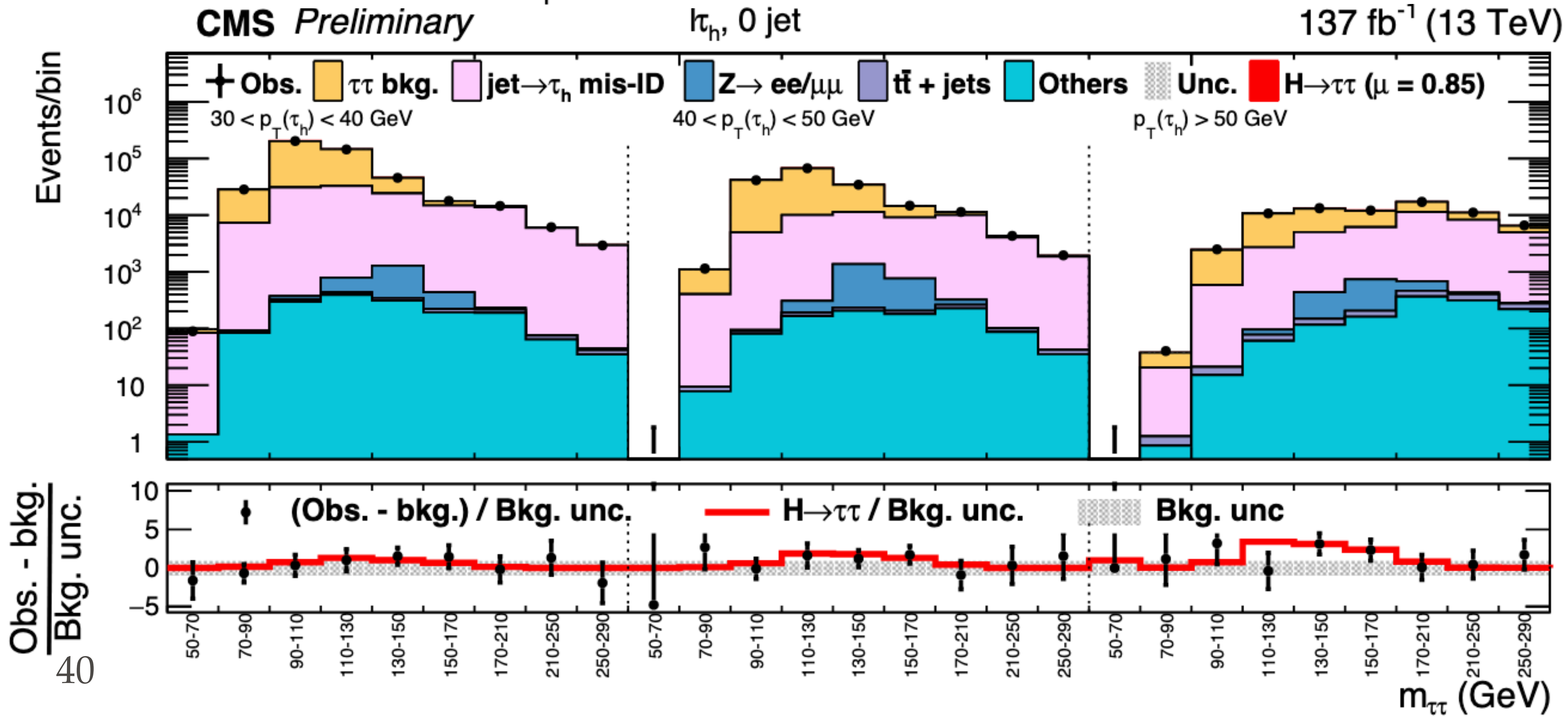
# The embedding technique

TAU-18-001

- Closure on μμ data
  - Good agreement within 2%
  - Finite detector effects not applied to low pTmiss
- Better performance of embedding than simulation when compared to data
- Upgraded from Run1 implementations (e.g. normalisation of background now from data)
- Methodology applied to H→ $\tau\tau$ with good agreement to data

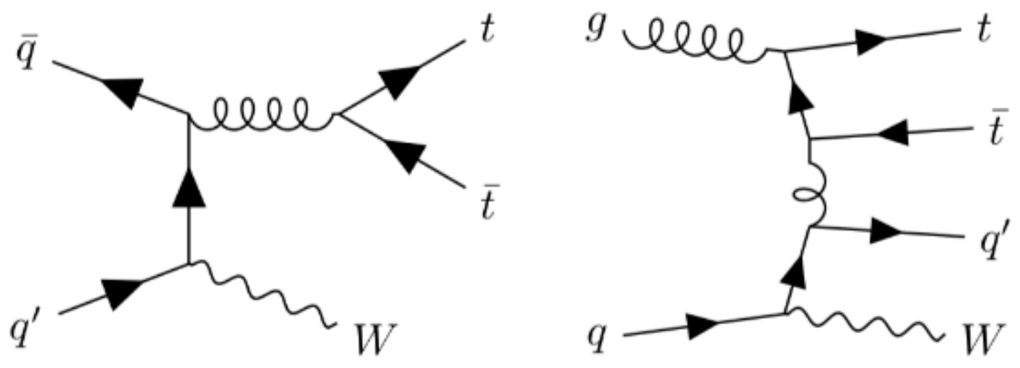


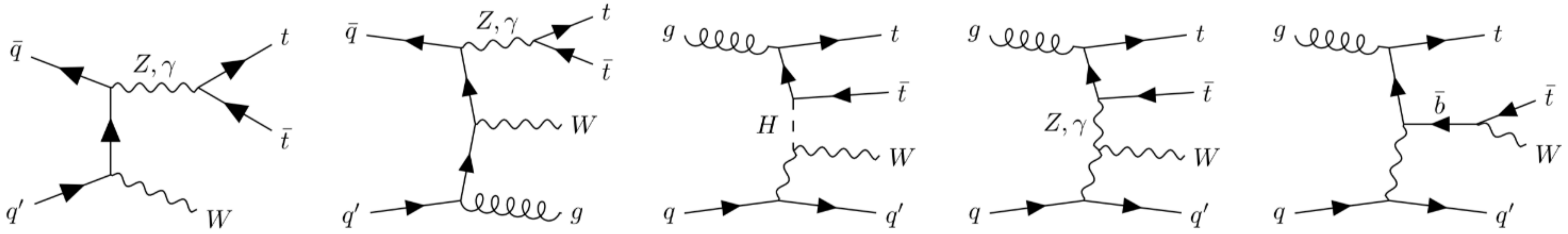




HIG-19-010

# ttW EW corrections





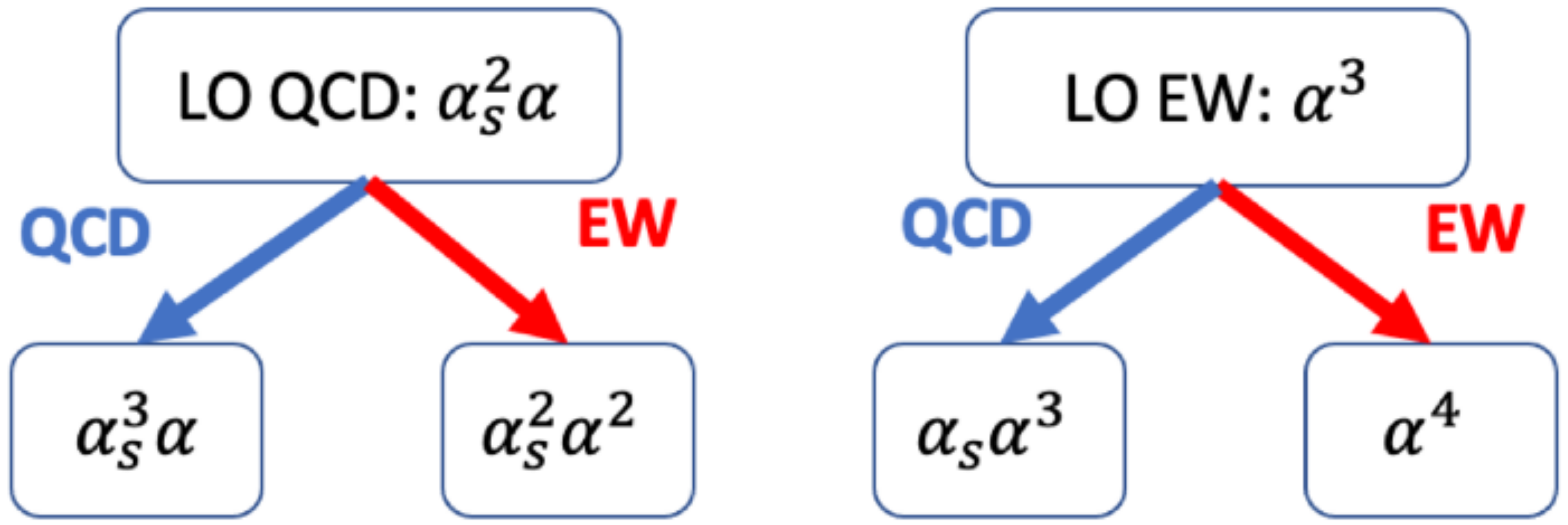
QCD (top): LO QCD ($O(\alpha_S^2\alpha)$) and NLO QCD ($O(\alpha_S^3\alpha)$)

EW (bottom): "tree-level EW" contributions ($O(\alpha^3) + O(\alpha_S\alpha^3)$)

$$\sigma^{NLO}_{QCD+EW} = \sigma^{NLO}_{QCD} + \delta\sigma_{EW}$$

$$\sigma^{NLO}_{QCD} = \underbrace{O(\alpha_S^2\alpha)}_{\text{LO QCD}} + \underbrace{O(\alpha_S^3\alpha)}_{\text{NLO QCD}}$$

$$\delta\sigma_{EW} = \underbrace{O(\alpha_S^2\alpha^2)}_{\text{NLO EW}} + \underbrace{O(\alpha^3) + O(\alpha_S\alpha^3)}_{\text{tree-level EW}} + \underbrace{O(\alpha^4)}_{\text{negligible}}$$



# ttbb settings

Table 2: Scale choices used in the event generation of $t\bar{t}b\bar{b}$ and $t\bar{t}$ processes for the different generators.

| ME Generator | $\mu_R$ | $\mu_F$ |
|---|---|---|
| ATLAS Powheg-Box-Res $t\bar{t}b\bar{b}$ | $\frac{1}{2}\sqrt[4]{m_{T,t}\cdot m_{T,\bar{t}}\cdot m_{T,b}\cdot m_{T,\bar{b}}}$ | $\frac{1}{2}(m_{T,t}+m_{T,\bar{t}}+m_{T,b}+m_{T,\bar{b}}+m_{T,g})$ |
| Sherpa 2.2.10 | $\frac{1}{2}\sqrt[4]{m_{T,t}\cdot m_{T,\bar{t}}\cdot m_{T,b}\cdot m_{T,\bar{b}}}$ | $\frac{1}{2}(m_{T,t}+m_{T,\bar{t}}+m_{T,b}+m_{T,\bar{b}}+m_{T,g})$ |
| ATLAS Powheg $t\bar{t}$ | $\sqrt{0.5\cdot(m^2_{T,t}+m^2_{T,\bar{t}})}$ | $\sqrt{0.5\cdot(m^2_{T,t}+m^2_{T,\bar{t}})}$ |
| ATLAS aMC $t\bar{t}$ | $\sqrt{0.5\cdot(m^2_{T,t}+m^2_{T,\bar{t}})}$ | $\sqrt{0.5\cdot(m^2_{T,t}+m^2_{T,\bar{t}})}$ |

| Variation | |
|---|---|
| Scale variation ME | $\mu_R\times 0.5\ \mu_F\times 0.5;\ \mu_R\times 2\ \mu_F\times 2$ |
| ISR variation (PS) | $\alpha_s^{ISR}\times 0.5, 2.0$ |
| FSR variation (PS) | $\alpha_s^{FSR}\times 0.5, 2.0$ |

hdamp variations in CMS:
0.8738 and 2.305 times the top quark mass