# Background and Signal Shapes

Nicolas **Morange**, *IJCLab*

Workshop on Systematic Effects and Nuisance Parameters in Particle Physics Data Analyses, 25/04/2023

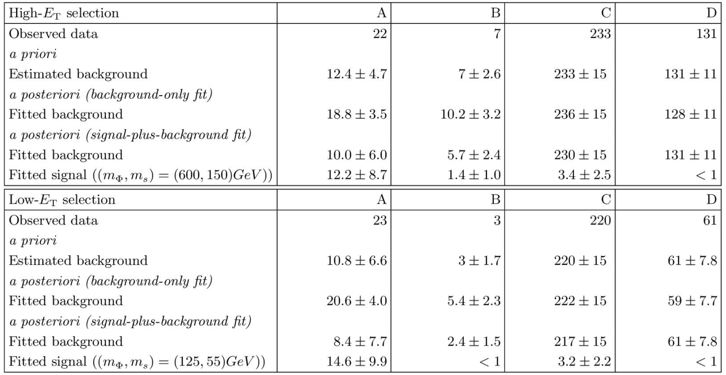
# Background and Signal shapes ?

**Every analysis is a (multidimensional) shape analysis**

- Traditional split between “cut-and-count” and shape analyses
    - Cut-and-count: evaluate number of events in signal region after selections
    - Shape fits: fit full distribution to extract signal
        - Usually more sensitive

- Hidden shapes
    - No analysis is just 1 signal region
    - Multiple signal regions, control regions
    - Extrapolating from one region to another is a shape effect

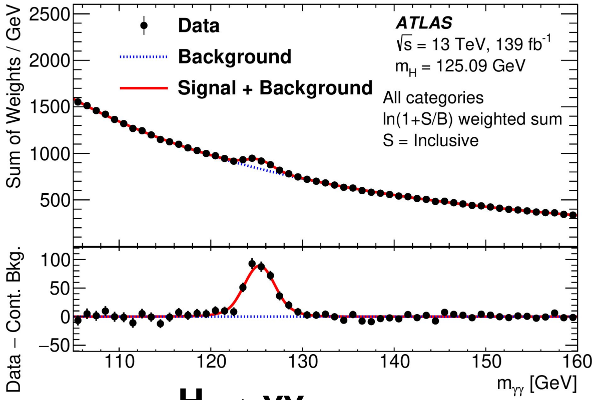
- We need accurate signal and background shapes in all cases !



| High-$E_T$ selection | A | B | C | D |
|---|---|---|---|---|
| Observed data | 22 | 7 | 233 | 131 |
| *a priori* | | | | |
| Estimated background | $12.4 \pm 4.7$ | $7 \pm 2.6$ | $233 \pm 15$ | $131 \pm 11$ |
| *a posteriori (background-only fit)* | | | | |
| Fitted background | $18.8 \pm 3.5$ | $10.2 \pm 3.2$ | $236 \pm 15$ | $128 \pm 11$ |
| *a posteriori (signal-plus-background fit)* | | | | |
| Fitted background | $10.0 \pm 6.0$ | $5.7 \pm 2.4$ | $230 \pm 15$ | $131 \pm 11$ |
| Fitted signal $((m_\Phi, m_s) = (600, 150) GeV)$ | $12.2 \pm 8.7$ | $1.4 \pm 1.0$ | $3.4 \pm 2.5$ | $< 1$ |

| Low-$E_T$ selection | A | B | C | D |
|---|---|---|---|---|
| Observed data | 23 | 3 | 220 | 61 |
| *a priori* | | | | |
| Estimated background | $10.8 \pm 6.6$ | $3 \pm 1.7$ | $220 \pm 15$ | $61 \pm 7.8$ |
| *a posteriori (background-only fit)* | | | | |
| Fitted background | $20.6 \pm 4.0$ | $5.4 \pm 2.3$ | $222 \pm 15$ | $59 \pm 7.7$ |
| *a posteriori (signal-plus-background fit)* | | | | |
| Fitted background | $8.4 \pm 7.7$ | $2.4 \pm 1.5$ | $217 \pm 15$ | $61 \pm 7.8$ |
| Fitted signal $((m_\Phi, m_s) = (125, 55) GeV)$ | $14.6 \pm 9.9$ | $< 1$ | $3.2 \pm 2.2$ | $< 1$ |

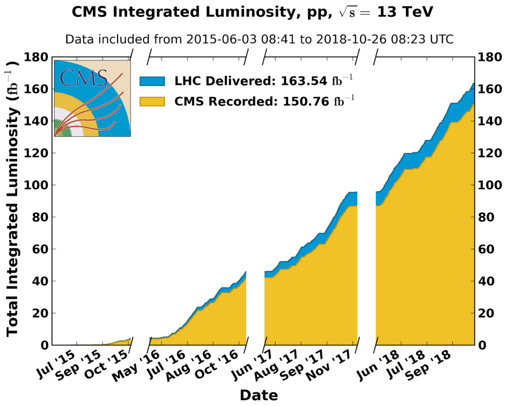
**LLP “CalRatio” search**

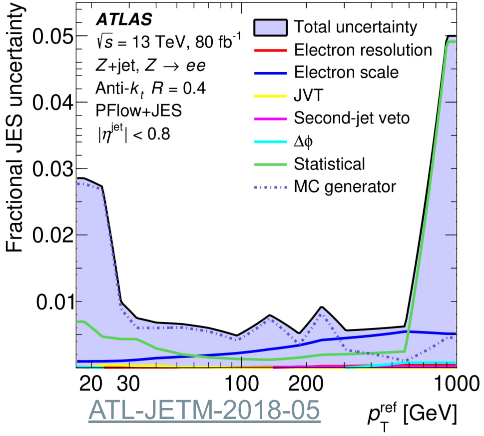


**H → γγ**

# With shapes come modelling uncertainties

- Large datasets
    - ~140 fb$^{-1}$ collected by ATLAS and CMS in Run 2
    - Already 40 fb$^{-1}$ of Run 3 data
    - Statistical uncertainties smaller and smaller
- Large datasets: precision calibrations
    - Electron and muon uncertainties at per-mille level
    - Jet energy scales at sub-percent precision
    - B-tagging efficiency uncertainty at <1%
    - => Large reduction in experimental uncertainties
- Therefore signal and background shapes need to be known with adequate precision
    - Meaning small modelling uncertainties

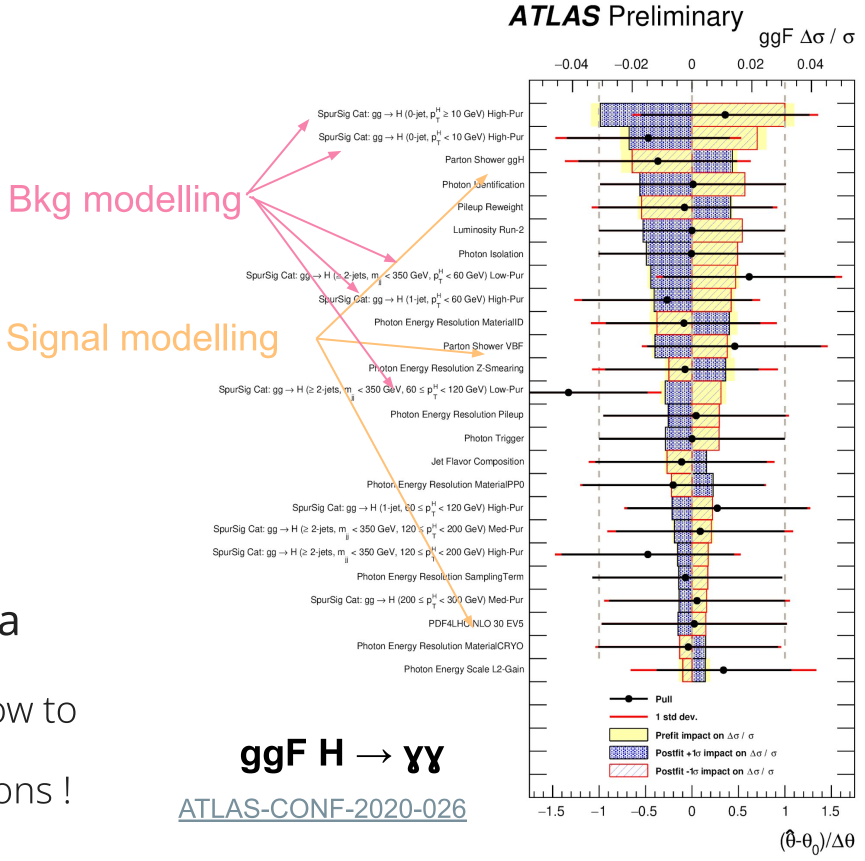




ATL-JETM-2018-05

# Modelling: leading concern in many analyses

- Goal #1: good modelling out-of-the-box
    - NLO generators for ~ all processes:
      Huge success from past years
      Large effort on parameter tuning from the collaborations
    - MVA/ML techniques require excellent modelling of correlations
- Goal #2: small modelling uncertainties
    - Easier to achieve when Goal #1 fulfilled
    - Keeping them small at the heart of analysis design
    - Lots of techniques involved
- Note: Differential measurements are not a miraculous solution
    - Fine enough differential measurements allow to get rid of signal modelling uncertainties
    - But uncertainties come back in interpretations !

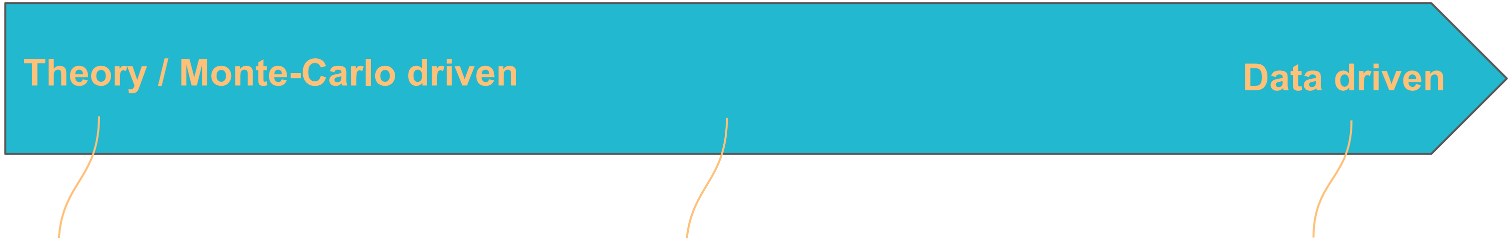


**ggF H → γγ**

ATLAS-CONF-2020-026

# The best Monte-Carlo is the data

**Analyses make use of the data as much as possible**



**Theory / Monte-Carlo driven**

**Data driven**

- Signal uncertainties
- Bkgs without good CRs

⇒ Uncertainties from MC variations or comparisons
⇒ Apply on full phase space
⇒ See presentations by **G. Jones** and **F. Tackmann**

- Bkgs with good CRs

⇒ Uncertainties from MC variations or comparisons
⇒ Constrained by profiling
⇒ Apply on extrapolation from CR to SR
⇒ See e.g presentations on Optimal Transport by **T. Manole** and **P. Windischhoffer**

- Embedding techniques
- Smooth background descriptions (e.g analytical)

⇒ Dedicated uncertainty evaluation

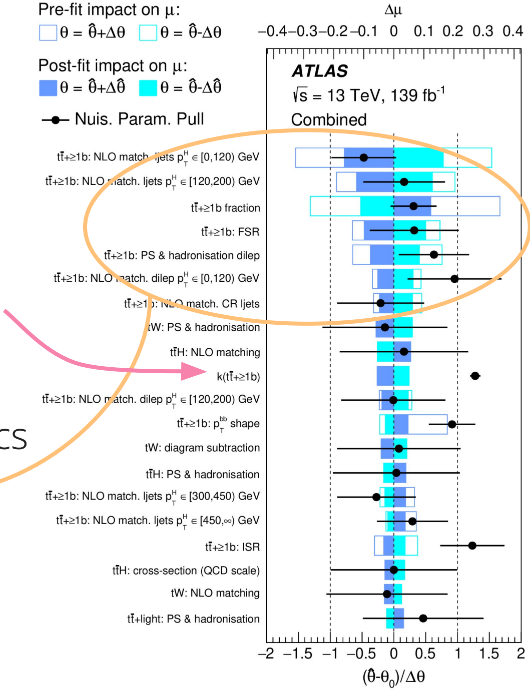
Slides heavily based on a presentation given at Higgs 2021 jointly with **Adinda De Wit** (LLR) Credits to her !!

**Full spectrum of techniques to get shapes and uncertainties**

# Background shapes

# MC-based textbook example: $t\bar{t}b\bar{b}$, for ttHbb

- $t\bar{t}b\bar{b}$ dominant bkg and low S/B
    - Complex process to model by MC
    - Control Regions not enough
- Very large theory uncertainty
    - Cross-section well constrained by profiling, measured ~1.3x expectation
    - Modelling systematics == collection of 2-point systematics
    - ME matching and PS uncertainties esp. give large shape/extrapolation effect
- Different setup by ATLAS/CMS but similar modelling impact:
    - ATLAS: $\Delta\mu = 0.25$
    - CMS: $\Delta\mu = 0.15$



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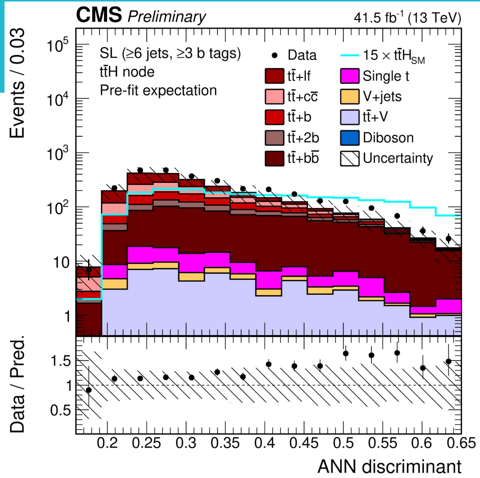
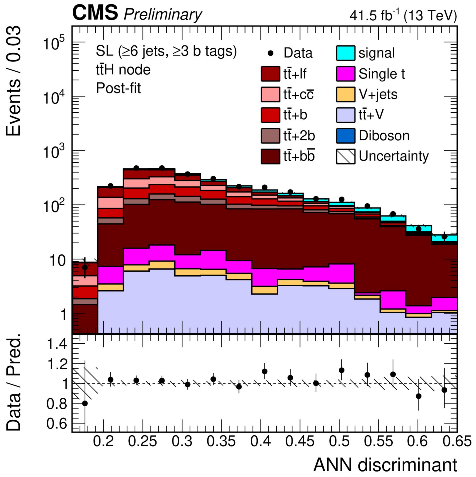
Prefit



CMS-PAS-HIG-18-030

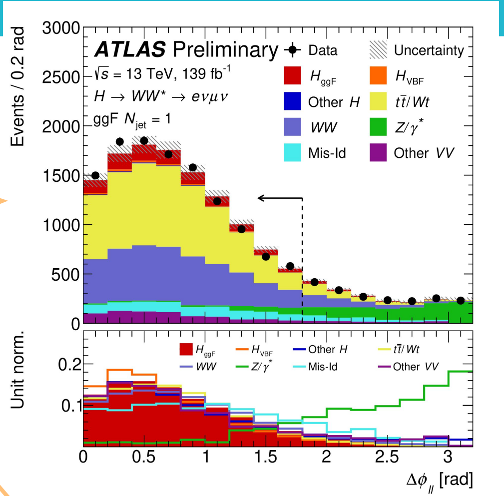
Postfit

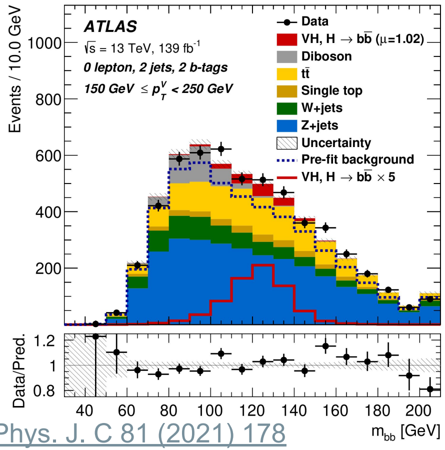


# Good modelling everywhere is hard: $t\bar{t}$

- The LHC is a top factory
  - $t\bar{t}$ is a bkg to almost any final state
  - Limited experimental efficiencies (b-veto)
  - Weird corners of the phase space (acceptance)
- $t\bar{t}$ modelling
  - Good modelling of bulk of phase space by the NLO generators after tuning
    - Though sizable discrepancies remain in some cases
  - Difficulty: uncertainties in tails / corners of phase space
    - Not easy to get enough MC statistics:
      - filtering / slicing strategies
      - Future common ATLAS/CMS MC samples may help: [ATL-PHYS-PUB-2021-016]()
    - Extrapolation from ‘bulk’ (CR) to ‘corner’ (SR) of phase space
    - Ambiguity between $t\bar{t}$ and Wt processes
  - Result in sizable $t\bar{t}$ modelling uncertainties in those analyses

[ATLAS-CONF-2021-014]()





[Eur. Phys. J. C 81 (2021) 178]()

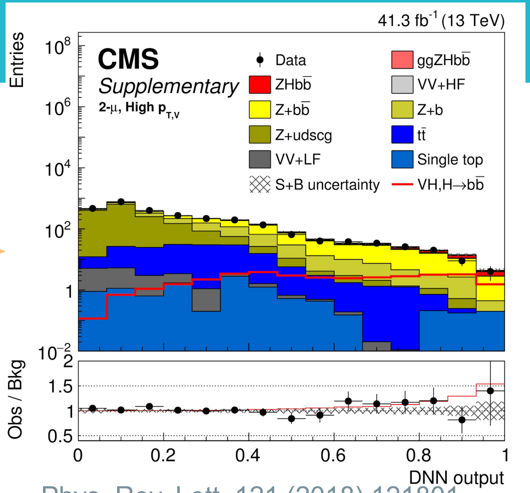
# VHbb: W/Z+hf backgrounds

**Good MC modelling: costly but worth it**

- W/Z+b$\bar{b}$ largest bkgs in VHbb search
- Difficulty: generate enough MC events in relevant phase space (high pT(V)), filtered for W/Z+hf

- CMS analysis (2018) uses MadGraph LO samples
  - Reweighting in pT(V) used
  - Large uncertainty associated

- ATLAS uses Sherpa NLO samples
  - Countless CPU hours required for MC generation
  - Filters (in)efficiency, spread of MC weights



Phys. Rev. Lett. 121 (2018) 121801

| Uncertainty source | $\Delta\mu$ | |
|---|---|---|
| Statistical | +0.26 | −0.26 |
| Normalization of backgrounds | +0.12 | −0.12 |
| Experimental | +0.16 | −0.15 |
| b-tagging efficiency and misid | +0.09 | −0.08 |
| V+jets modeling | +0.08 | −0.07 |
| Jet energy scale and resolution | +0.05 | −0.05 |
| Lepton identification | +0.02 | −0.01 |
| Luminosity | +0.03 | −0.03 |
| Other experimental uncertainties | +0.06 | −0.05 |
| MC sample size | +0.12 | −0.12 |
| Theory | +0.11 | −0.09 |
| Background modeling | +0.08 | −0.08 |
| Signal modeling | +0.07 | −0.04 |
| Total | +0.35 | −0.33 |

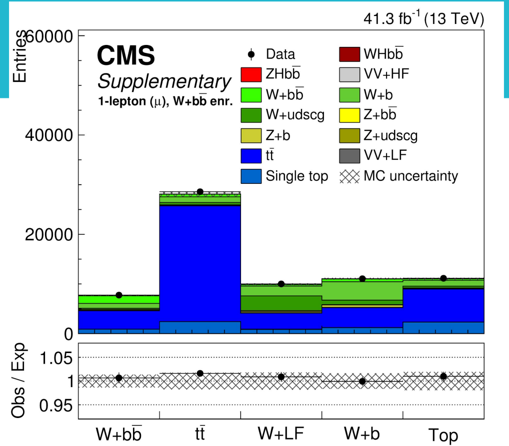
# VHbb: W/Z+hf backgrounds estimation

## Controlled use of systematics profiling

- Taking advantage of good control regions
    - Control regions “pretty close” to signal regions
        - Use of ΔRbb / mbb sidebands + multiclass BDT
    - Purity to specific backgrounds from “good” to “excellent”

- Profiling at work
    - CRs allow to constrain background cross-sections
    - And some background shapes
    - What remain are smaller extrapolation uncertainties

- Caveats
    - Choice of the 2-point systematics, e.g Sherpa/MadGraph difference much larger than Sherpa scale / matching variations
    - MC stat noise in uncertainty evaluation smoothed by use of ML techniques for n-dim reweighting



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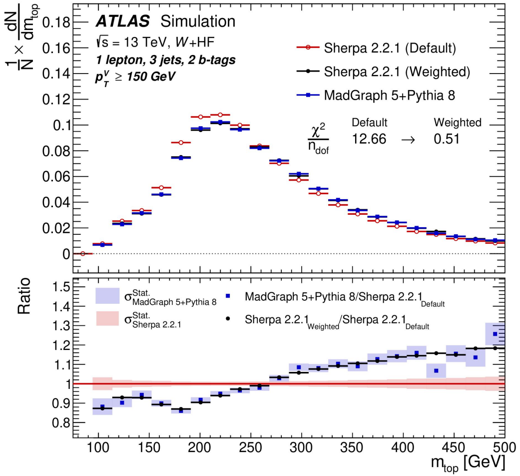
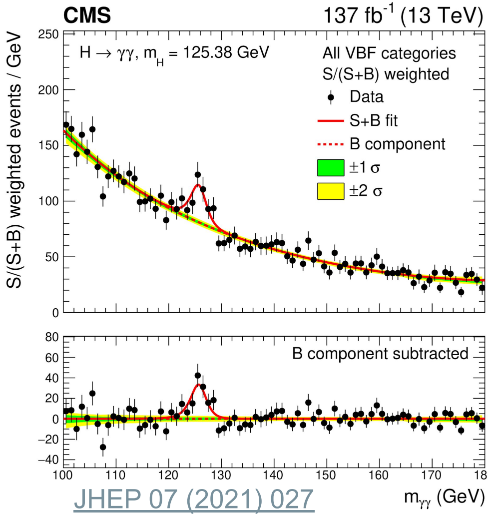


Eur. Phys. J. C 81 (2021) 178

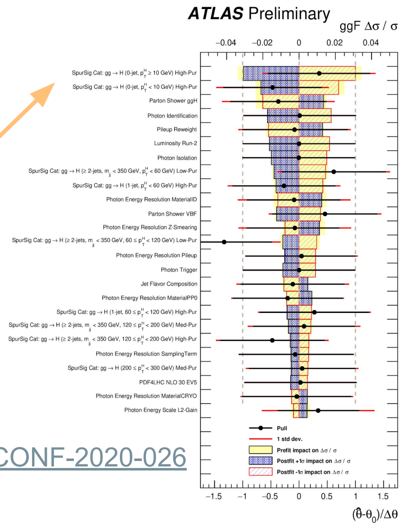
# Modelling smooth backgrounds

See Model selection talk by C. Schafer

- Textbook H → ɣɣ example
  - Narrow resonance on top of smoothly falling bkg
  - Use of semiparametric models
  - Fit of analytical functions more accurate than ɣɣ / ɣ-jet MC samples
  - Also applies to H→μμ, H→Zɣ…
- Procedures well established since Run-1
  - ATLAS-CMS disagreement also when established
  - **CMS**: Discrete profiling. Choice of function embedded in a nuisance parameter
    - Residual uncertainty very small
  - **ATLAS**: Select function, and estimate maximum bias ‘spurious signal’
    - Requires vast amounts of MC events
    - Limitation for high luminosity



JHEP 07 (2021) 027

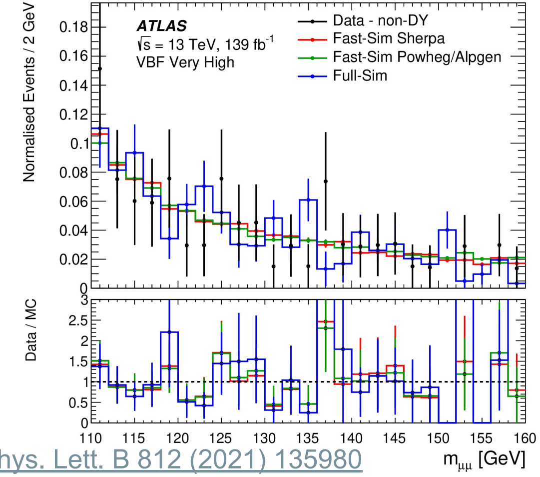


ATLAS-CONF-2020-026

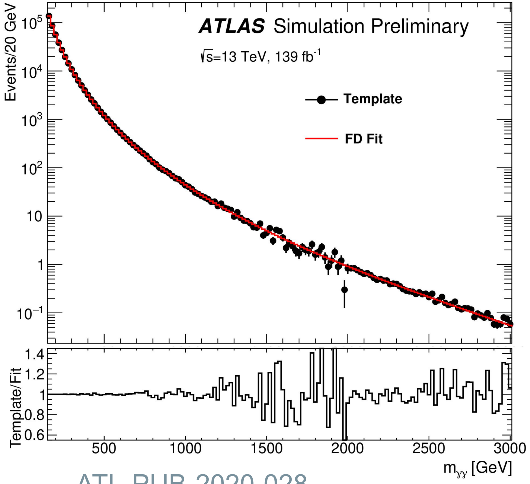
# Smooth backgrounds: new techniques

## New techniques to overcome limitations of spurious signal evaluation

- Use of very fast sim (H→μμ):
  - LO DY samples at parton-level, with parameterised detector effects
  - Spurious signal evaluated on these samples
- Functional Decomposition
  - Use series expansion to parameterize bkg shape
  - Either replacement of functional form, or use for spurious signal evaluation
- Gaussian Processes
  - Kernel encodes width of features
  - Either replacement of functional form, or use for spurious signal evaluation



Phys. Lett. B 812 (2021) 135980

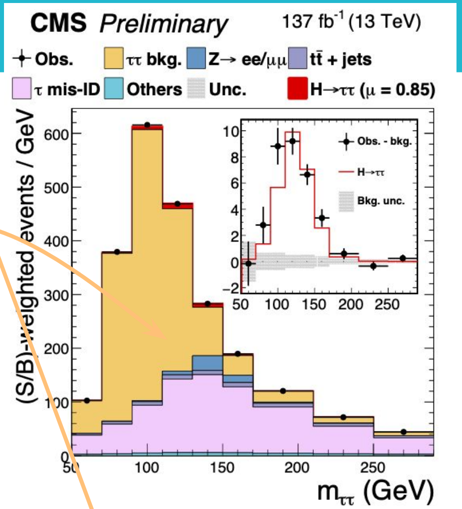


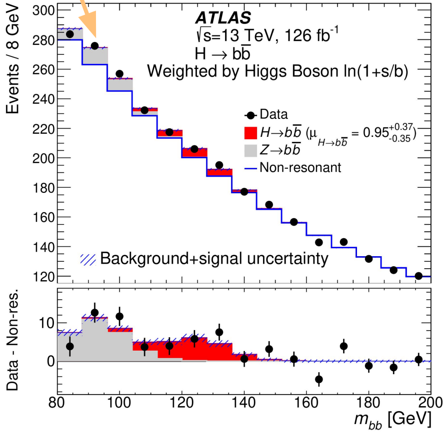
ATL-PUB-2020-028

# Resonant backgrounds - embedding

- E.g. Z boson decays in fermionic channels
- Same signature as the signal, except for mass  
⇒ hard to model using data control regions
    - “Good” control for the background likely not signal-depleted
- MC simulation does not always adequately describe data
- Even if it does - would need very large samples to avoid large MC statistical uncertainties
- Hybrid solution: Embedding

CMS-PAS-HIG-19-010





Eur. Phys. J. C.81(2021) 537

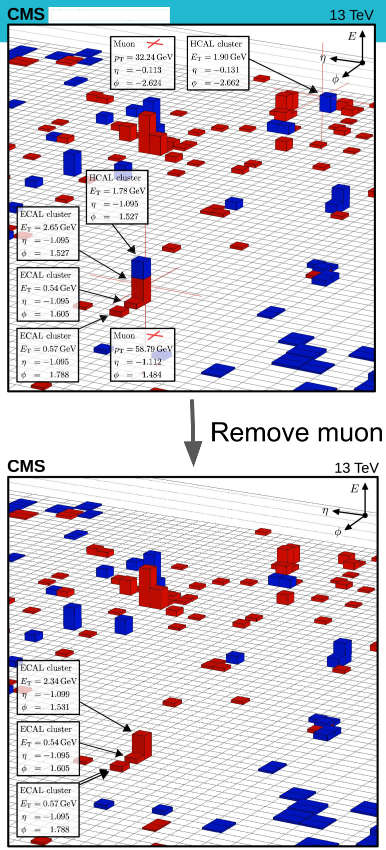
# Embedding - principle

JINST 14 (2019) P06032

- Principle in a nutshell:
  - Select a well-understood process in data, in our case Z→μμ
  - Replace the muons by simulated particles of interest: τ's (ATLAS,CMS), b's (ATLAS)

- A simple idea?
  - Simulated/Real geometry don't match 100% → cannot merge at level of hits/deposits
    - Cannot obtain perfect closure → residual corrections
  - Spin correlations for simulated taus ignored

- Less complex procedure (re-scaling, not replacing) also in use in ATLAS (ττ)
  - Trade complexity for accuracy

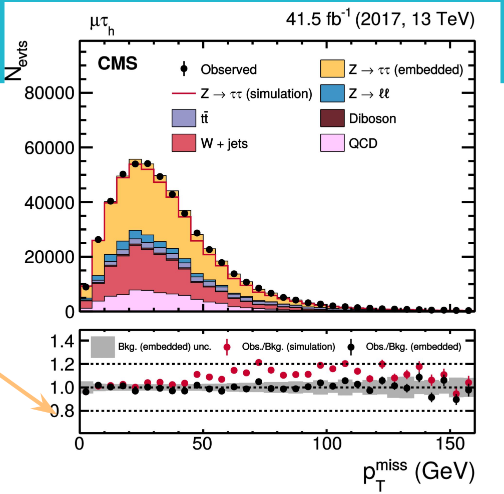


Remove muon deposits

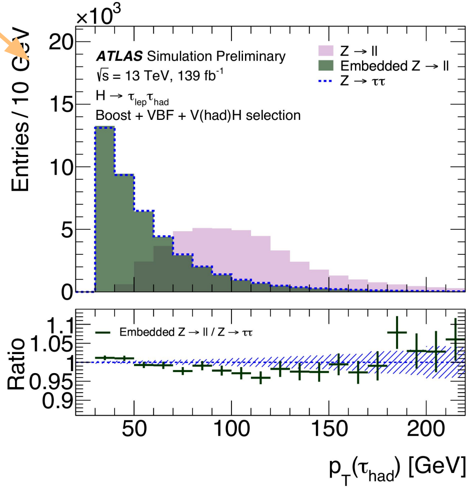
Calorimeter deposits before and after removing muon deposits

# Embedding - achievements

JINST 14 (2019) P06032



- Better modelling of kinematic distributions with embedded samples than simulation
- Helps reduce some uncertainties
- Simplified procedure provides a control region in data
- Even better modelling (smaller uncertainties?) → more work needed!



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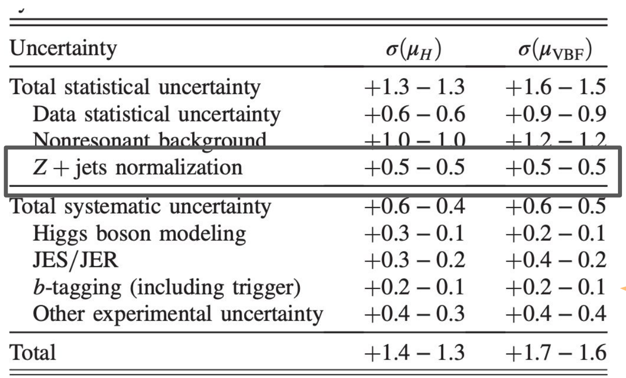


| Uncertainty | $\sigma(\mu_H)$ | $\sigma(\mu_{\text{VBF}})$ |
|---|---|---|
| Total statistical uncertainty | $+1.3-1.3$ | $+1.6-1.5$ |
| Data statistical uncertainty | $+0.6-0.6$ | $+0.9-0.9$ |
| Nonresonant background | $+1.0-1.0$ | $+1.2-1.2$ |
| $Z+$jets normalization | $+0.5-0.5$ | $+0.5-0.5$ |
| Total systematic uncertainty | $+0.6-0.4$ | $+0.6-0.5$ |
| Higgs boson modeling | $+0.3-0.1$ | $+0.2-0.1$ |
| JES/JER | $+0.3-0.2$ | $+0.4-0.2$ |
| $b$-tagging (including trigger) | $+0.2-0.1$ | $+0.2-0.1$ |
| Other experimental uncertainty | $+0.4-0.3$ | $+0.4-0.4$ |
| Total | $+1.4-1.3$ | $+1.7-1.6$ |

VBF H→bb analysis with 2016 data - Z+jets normalization uncertainty significant. Removed thanks to embedding (trade: 20% closure uncertainty)

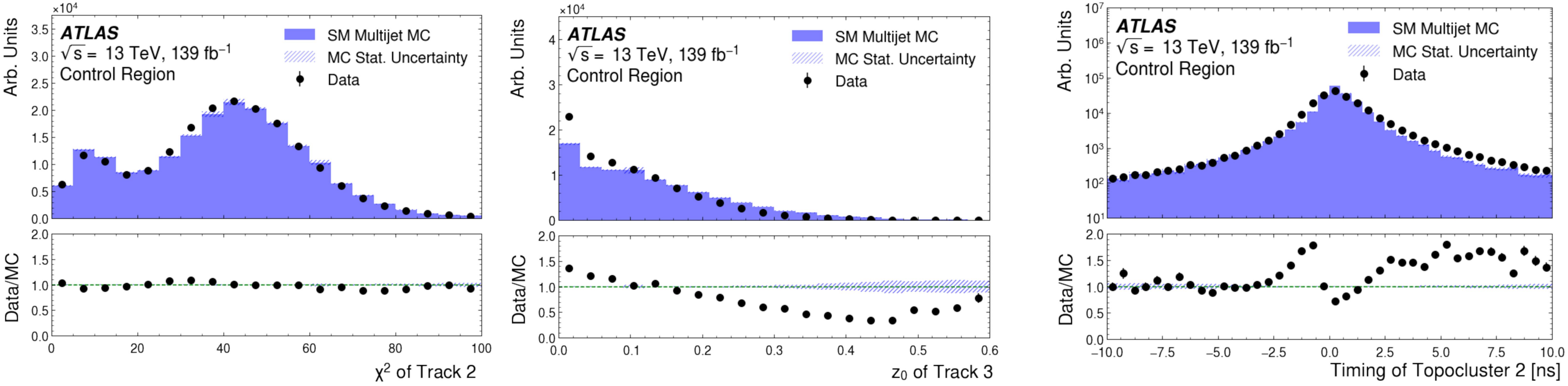
Phys. Rev. D98 052003 (2018)

# Dealing with hybrid cases: CalRatio analysis

JHEP 06 (2022) 005

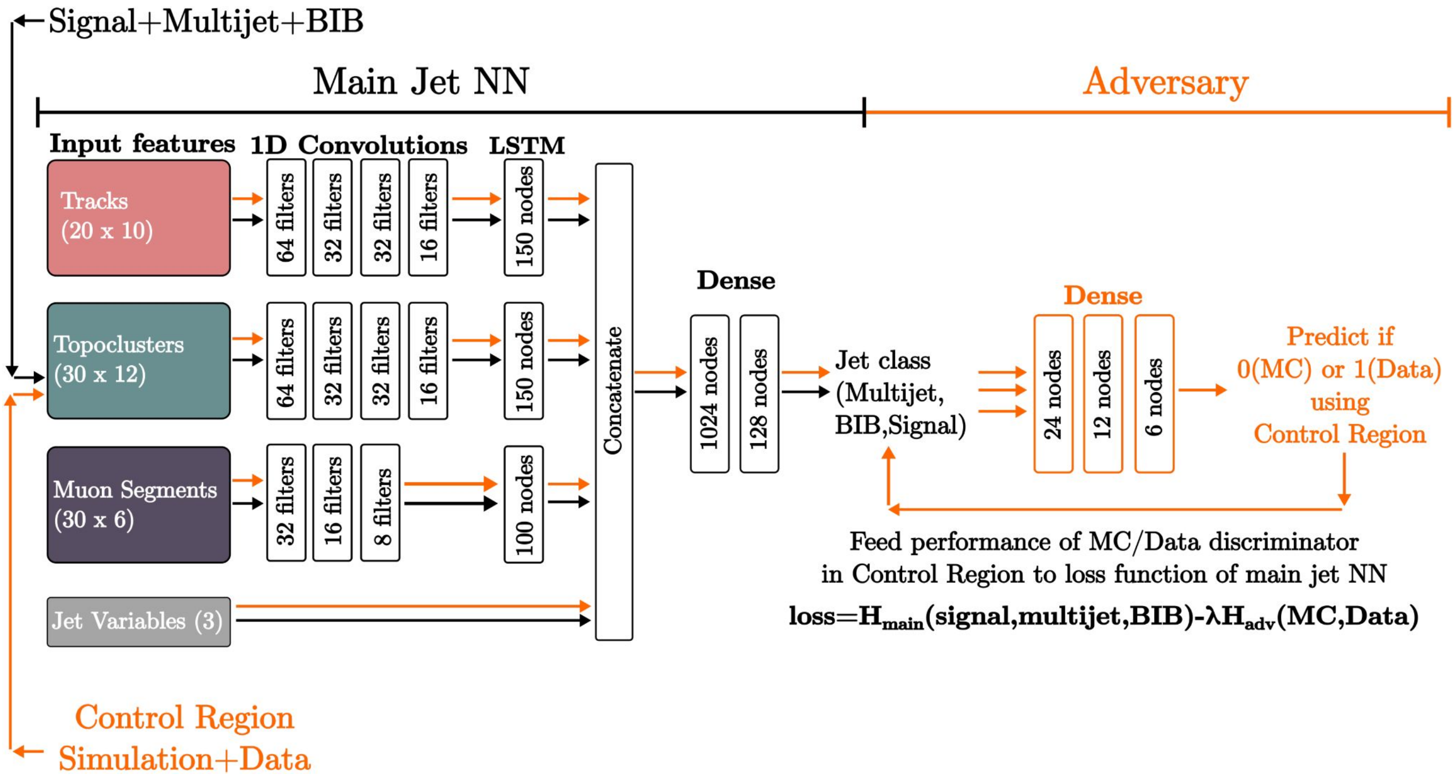
- Search for LLP using strange “CalRatio” jets
- Build multiclass NN to separate signal CalRatio jets (**MC**), QCD (**MC**), Beam-Induced-Background (from **data CR** defined at trigger level)
  - But BIB-data sample is known to have significant fraction of QCD-data contamination
  - And certain input variables, such as jet timing, are important discriminators, but are not perfectly modelled

➢ **NN learns to separate data/MC because of QCD events in BIB sample…**



# Adversarial NN to the rescue

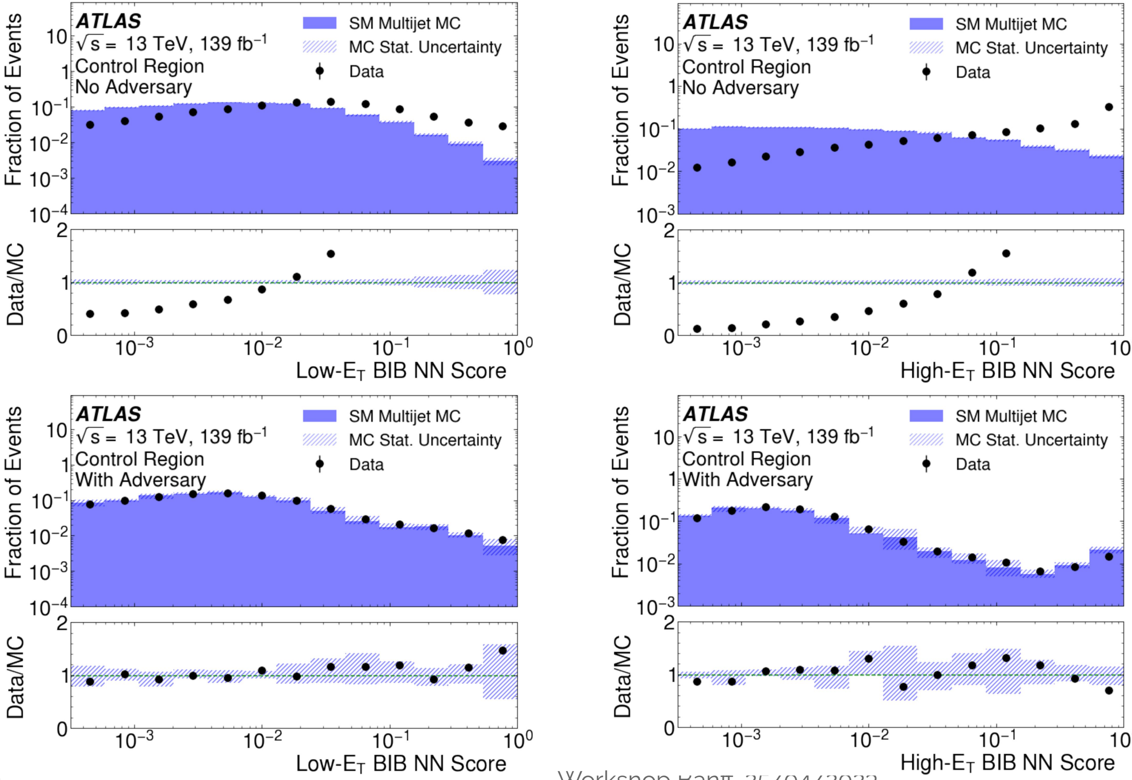
- Adversary trained to distinguish data from MC in dijet control region
- Feeds into main NN as penalty in loss function



$$\text{loss}=H_{\text{main}}(\text{signal},\text{multijet},\text{BIB})-\lambda H_{\text{adv}}(\text{MC},\text{Data})$$

# Adversarial NN results

- Huge improvement
- Residual discrepancies covered by systematic uncertainty



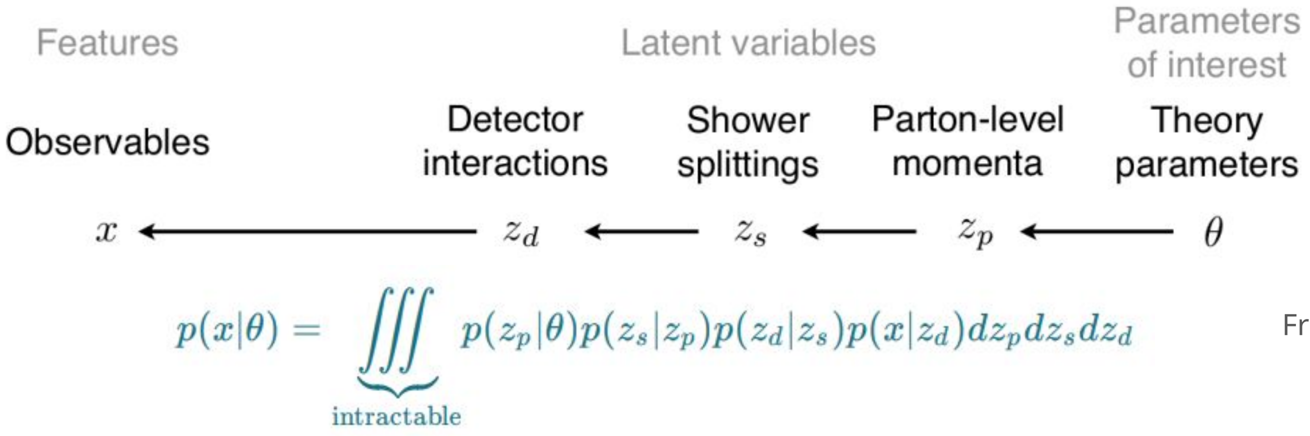
**No adversary**

**Adversary**

# Signal shapes

# Signal shapes ?

**Signal shapes are the convolution of theory predictions in the form of MC samples, and of experimental (detector) effects**



Features | Latent variables | Parameters of interest

Observables | Detector interactions | Shower splittings | Parton-level momenta | Theory parameters

$$x \longleftarrow z_d \longleftarrow z_s \longleftarrow z_p \longleftarrow \theta$$

$$p(x|\theta) = \underbrace{\iiint}_{\text{intractable}} p(z_p|\theta)p(z_s|z_p)p(z_d|z_s)p(x|z_d)dz_p dz_s dz_d$$

From Gilles Louppe

- Uncertainties affect all terms in the convolution
- For background shapes, control regions and data-driven techniques allow to short-circuit some of the uncertainties
- For signal shapes we need to have them all

# Examples in Higgs: Underlying event & parton shower

- Significant component of the theoretical uncertainty in several measurements, e.g. H→γγ
    - Particularly in VBF phase space
- Several ways in use to estimate these:
    - Difference between two showering/hadronization programs
    - Difference between a main tune and alternative tune, using the same showering/hadronization program
    - In this case: ATLAS: PY8 vs Herwig7, CMS: PY8 tune variation

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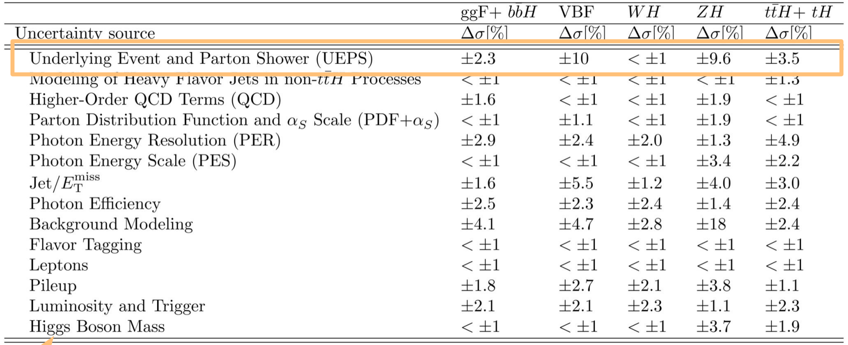
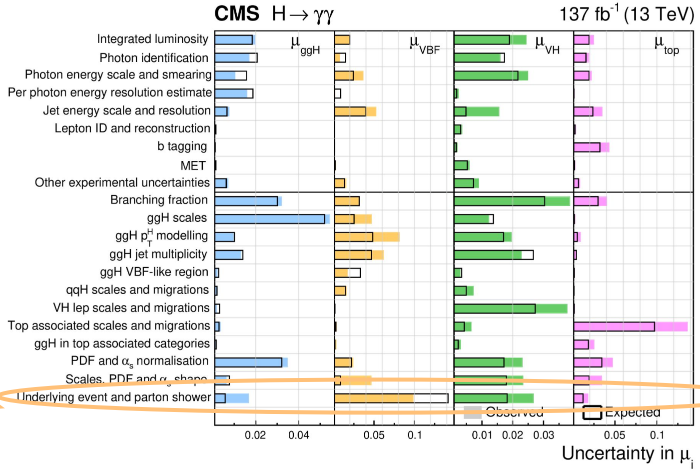


| Uncertainty source | ggF+ $b\bar{b}H$ $\Delta\sigma[\%]$ | VBF $\Delta\sigma[\%]$ | $WH$ $\Delta\sigma[\%]$ | $ZH$ $\Delta\sigma[\%]$ | $t\bar{t}H+tH$ $\Delta\sigma[\%]$ |
|---|---|---|---|---|---|
| Underlying Event and Parton Shower (UEPS) | ±2.3 | ±10 | < ±1 | ±9.6 | ±3.5 |
| Modeling of Heavy Flavor Jets in non-$t\bar{t}H$ Processes | < ±1 | < ±1 | < ±1 | < ±1 | ±1.3 |
| Higher-Order QCD Terms (QCD) | ±1.6 | < ±1 | < ±1 | ±1.9 | < ±1 |
| Parton Distribution Function and $\alpha_S$ Scale (PDF+$\alpha_S$) | < ±1 | ±1.1 | < ±1 | ±1.9 | < ±1 |
| Photon Energy Resolution (PER) | ±2.9 | ±2.4 | ±2.0 | ±1.3 | ±4.9 |
| Photon Energy Scale (PES) | < ±1 | < ±1 | < ±1 | ±3.4 | ±2.2 |
| Jet/$E_T^{miss}$ | ±1.6 | ±5.5 | ±1.2 | ±4.0 | ±3.0 |
| Photon Efficiency | ±2.5 | ±2.3 | ±2.4 | ±1.4 | ±2.4 |
| Background Modeling | ±4.1 | ±4.7 | ±2.8 | ±18 | ±2.4 |
| Flavor Tagging | < ±1 | < ±1 | < ±1 | < ±1 | < ±1 |
| Leptons | < ±1 | < ±1 | < ±1 | < ±1 | < ±1 |
| Pileup | ±1.8 | ±2.7 | ±2.1 | ±3.8 | ±1.1 |
| Luminosity and Trigger | ±2.1 | ±2.1 | ±2.3 | ±1.1 | ±2.3 |
| Higgs Boson Mass | < ±1 | < ±1 | < ±1 | ±3.7 | ±1.9 |

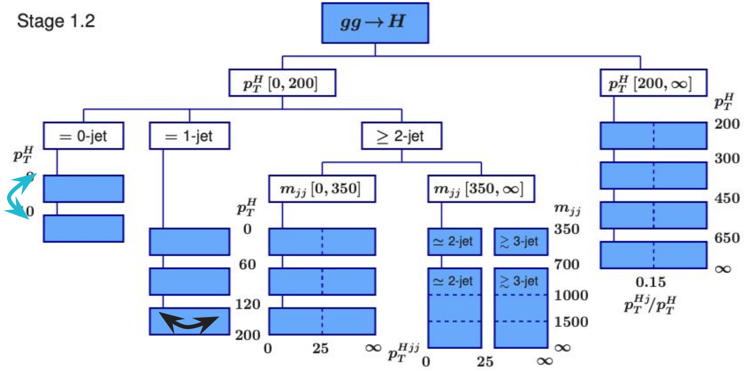


JHEP 07 (2021) 027

# Going for differential measurements: Higgs STXS

**Differential measurements: instead of measuring 1 signal cross-section, measure simultaneously Higgs cross-section in well-defined parts of phase space based on production kinematics**

- Higgs Simplified Template Cross-sections
  - Agreement between ATLAS CMS and theorists on “good” partition of phase space
  - Selected so that relevant theory uncertainties can be provided
  - Good sensitivity to new physics at high momentum
- Requires a much more refined set of theory uncertainties
  - Between STXS bins
    - Not a measurement uncertainty when measuring cross sections
    - Enters when merging bins
    - Enters for interpretations (μ,κ, EFT)
  - Within STXS bins
    - Accounts for differences in acceptance
- Overall net reduction of signal uncertainties



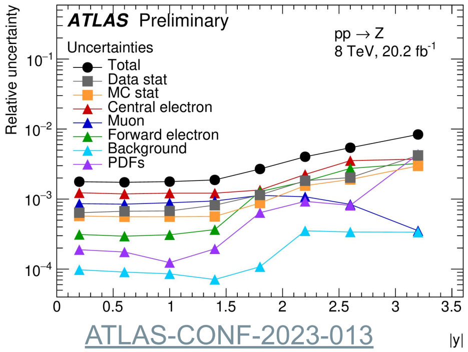
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWGFiducialAndSTXS

# Uncertainties in interpretations of measurements

**Differential measurements allow to factorize, but do not make uncertainties magically disappear**

- Measurement of transverse momentum and rapidity of *Z* boson using Run 1 data
  - Joint measurement of **1584** parameters (cross-sections + polarization coefficients) !
  - Extremely precise data
  - Negligible modelling uncertainties

- Interpretation of these measurements: determination of $\alpha_S$
  - Relate all these measurements to common underlying theory parameters
  - Modelling uncertainties dominate
    - Missing higher order corrections
    - Parton density functions



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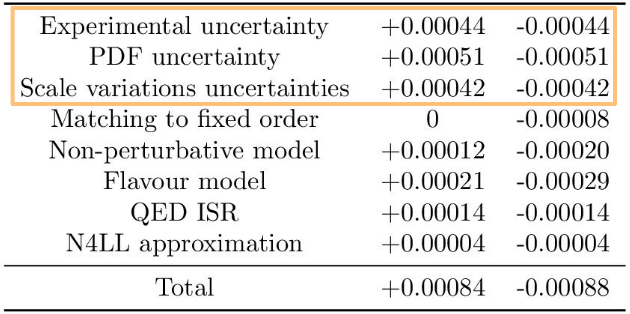


| | | |
|---|---|---|
| Experimental uncertainty | +0.00044 | -0.00044 |
| PDF uncertainty | +0.00051 | -0.00051 |
| Scale variations uncertainties | +0.00042 | -0.00042 |
| Matching to fixed order | 0 | -0.00008 |
| Non-perturbative model | +0.00012 | -0.00020 |
| Flavour model | +0.00021 | -0.00029 |
| QED ISR | +0.00014 | -0.00014 |
| N4LL approximation | +0.00004 | -0.00004 |
| Total | +0.00084 | -0.00088 |

ATLAS-CONF-2023-015

# Summary

- Getting the right signal and background shapes (i.e with small associated uncertainties) is a major topic when going for precision measurements or measurements of low processes with low S/B

- Large field of analysis techniques to use data more and rely less on MC predictions
  - Very active field esp. using techniques from the ML world

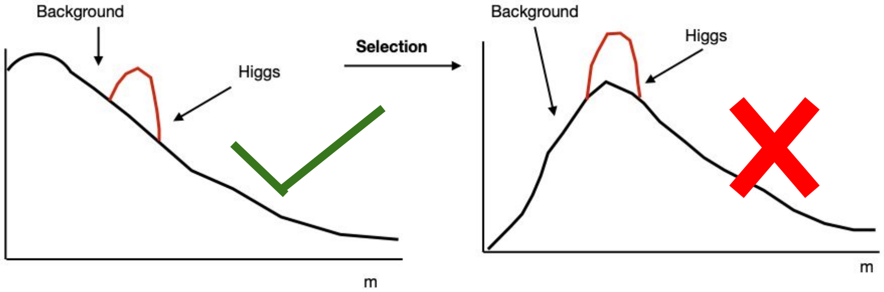
- Progress requires close collaboration experimentalists / theorists / statisticians
  - Simulations of complex final states ($t\bar{t}b\bar{b}$, W/Z+hf…)
  - Simulations of difficult phase space (Higgs VBF, high pT)
  - Agreement on “adequate” uncertainties in the shapes

# Additional Material

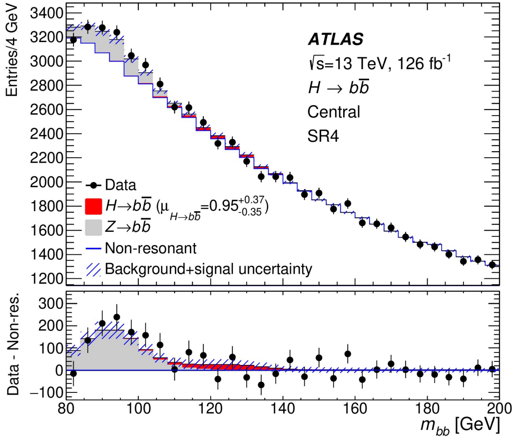
# Smooth backgrounds: sculpting

- Analysis selection should avoid sculpting background
  - Loss of sensitivity, difficulty modelling data-driven background

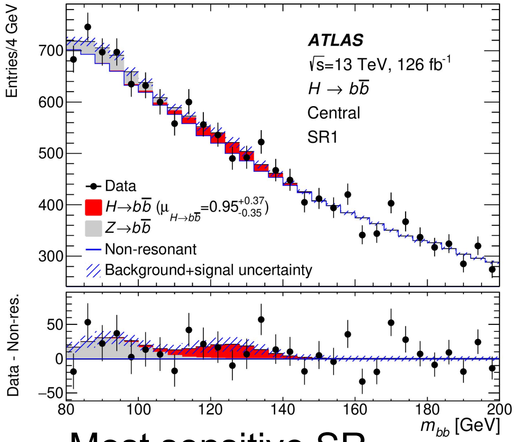
- Mitigation strategies in H→bb analyses
  - “Basic” selection: mass-decorrelated double-b taggers for boosted H→ bb
  - Event classification: mass-decorrelated ANN for VBF H→bb



Least sensitive SR



Similar non-resonant bkg shapes!



Most sensitive SR

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# ttH in multilepton final states: ttW/ttZ

- ttH ML: complex final states with many bkgs
- ttW/ttZ leading ones
  - Description by MC complex
  - Significant differences between generators
- Extensive use of multiclass ML techniques to separate signal / bkgs and fit ttW/ttZ
  - Impact of bkg modelling contained
  - Large μ(ttW)~1.5 in ATLAS and CMS

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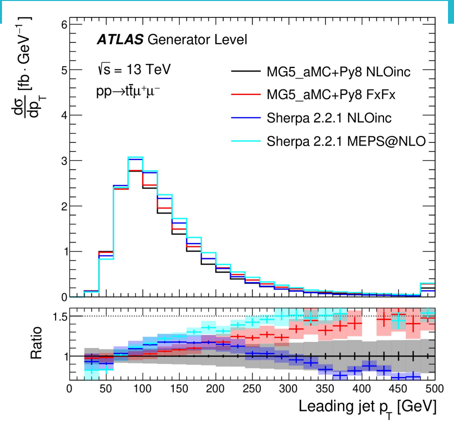

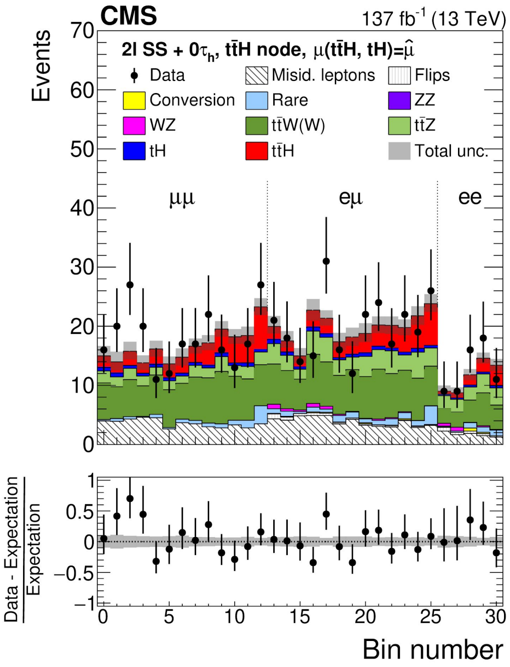

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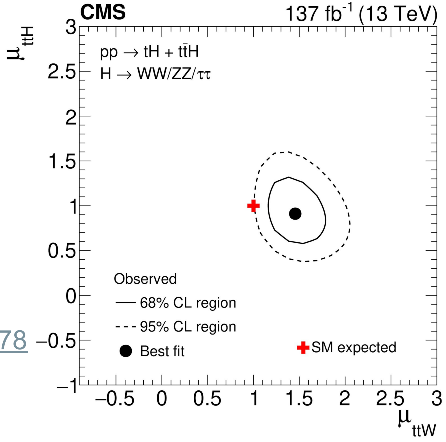


ATLAS-CONF-2019-045

# Phase space modelling - Higgs pT

- Modelling of Higgs boson pT spectrum particularly important for analyses looking at the boosted regime
    - Example of where recent progress has been incorporated in the analyses!
- However, large theory/modelling systematics in the ggH high pT spectrum remain → dwarfed by the statistical uncertainty in highly boosted analyses...

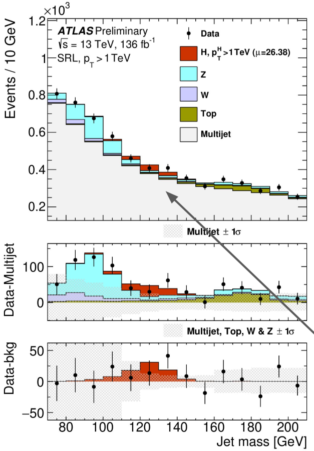
| Uncertainty Contribution | $p_T^H > 450$ GeV | $p_T^H > 1$ TeV |
|---|---|---|
| Total | 3.3 | 31 |
| Statistical | 2.8 | 30 |
| Jet Systematics | 1.2 | 7 |
| Modeling and Theory Systs. | 1.0 | 1 |
| Flavor Tagging Systs. | 0.5 | 3 |
| Total Systematics | 1.7 | 8 |

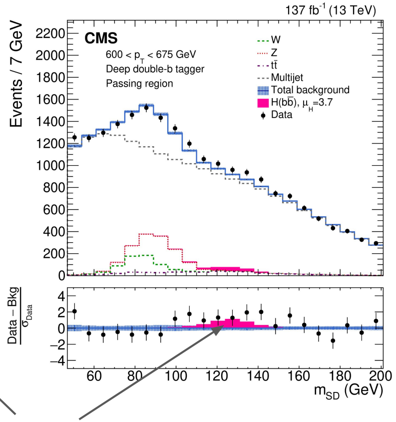
ATLAS-CONF-2021-010

**HJ-MiNLO**

**POWHEG 1J, pT reweight**

| | 2016 | 2017 | 2018 | Combined |
|---|---|---|---|---|
| Expected $\mu_Z$ | $1.00^{+0.38}_{-0.28}$ | $1.00^{+0.42}_{-0.29}$ | $1.00^{+0.43}_{-0.29}$ | $1.00^{+0.23}_{-0.19}$ |
| Observed $\mu_Z$ | $0.86^{+0.32}_{-0.24}$ | $1.11^{+0.48}_{-0.33}$ | $0.91^{+0.37}_{-0.26}$ | $1.01^{+0.24}_{-0.20}$ |
| HJ-MINLO | | | | |
| Expected $\mu_H$ | $1.0^{+3.3}_{-3.5}$ | $1.0 \pm 2.5$ | $1.0^{+2.3}_{-2.4}$ | $1.0 \pm 1.4$ |
| Observed $\mu_H$ | $7.9^{+3.4}_{-3.2}$ | $4.8^{+2.6}_{-2.5}$ | $1.7 \pm 2.3$ | $3.7^{+1.6}_{-1.5}$ |
| Expected H significance ($\mu_H = 1$) | $0.3\,\sigma$ | $0.4\,\sigma$ | $0.4\,\sigma$ | $0.7\,\sigma$ |
| Observed H significance | $2.4\,\sigma$ | $1.9\,\sigma$ | $0.7\,\sigma$ | $2.5\,\sigma$ |
| Expected UL $\mu_H$ ($\mu_H = 0$) | <6.8 | <5.0 | <4.7 | <2.9 |
| Observed UL $\mu_H$ | <8.0 | <4.8 | <1.7 | <3.7 |
| Ref.[23] H $p_T$ spectrum | | | | |
| Expected $\mu_H$ | $1.0 \pm 1.5$ | $1.0^{+1.1}_{-1.0}$ | $1.0^{+1.1}_{-1.0}$ | $1.0^{+0.7}_{-0.6}$ |
| Observed $\mu_H$ | $4.0^{+1.9}_{-1.6}$ | $2.2^{+1.4}_{-1.2}$ | $1.1 \pm 1.1$ | $1.9^{+0.9}_{-0.7}$ |
| Expected H significance ($\mu_H = 1$) | $0.7\,\sigma$ | $0.9\,\sigma$ | $1.0\,\sigma$ | $1.7\,\sigma$ |
| Observed H significance | $2.6\,\sigma$ | $1.8\,\sigma$ | $1.1\,\sigma$ | $2.9\,\sigma$ |
| Expected UL $\mu_H$ ($\mu_H = 0$) | <3.4 | <2.4 | <2.3 | <1.4 |
| Observed UL $\mu_H$ | <4.0 | <2.2 | <1.1 | <1.9 |



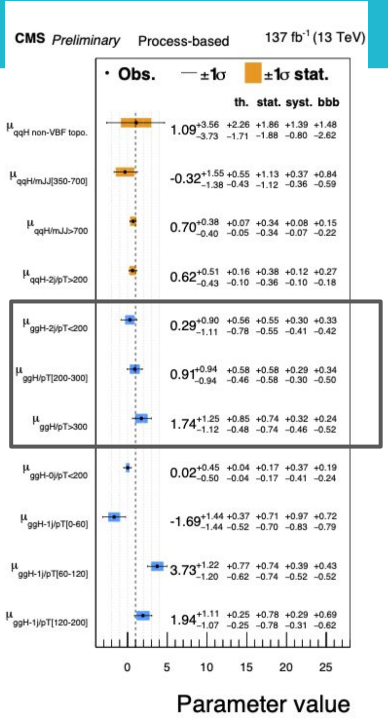


HJ-MiNLO

JHEP 12 (2020) 085

# Phase space modelling - Higgs pT

- … but not necessarily in less boosted phase spaces - e.g. signal strength measurement ggH+2jet / high pT in H→ττ
- In H→WW STXS cross section measurements also a more important component at high pT than in other bins



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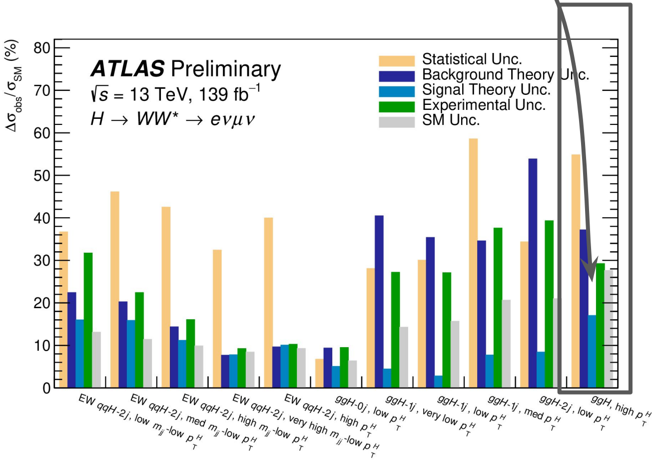
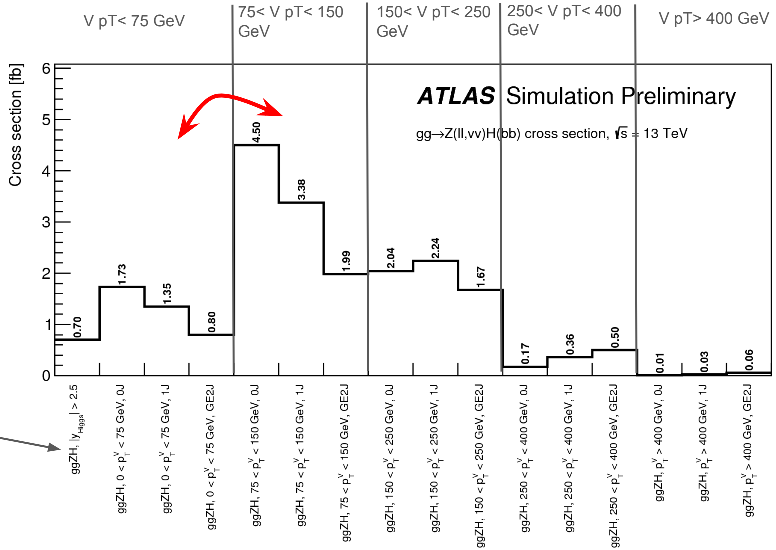


ATLAS-CONF-2021-014

# STXS uncertainties between bins

ATLAS-PHYS-PUB-2018-035

- Generally based on scale/pdf variations with uncertainties acting across bin boundary
  - E.g. change in cross section above the boundary when applying variations → uncertainty
  - Uncertainty acts across boundary (relative)
  - Difficulty in certain cases
- Important to agree on values of these → e.g. re-interpreting measurements/comparing interpretations
- Common scheme being completed in LHC Higgs WG



E.g. cross section 0-75 GeV < 75-150 GeV; migration across 75 GeV bin boundary can lead to a very large uncertainty in the first bin:
25% uncertainty above the 75 GeV boundary → 100% uncertainty below.

# STXS uncertainties within bins

- Multiple possible approaches:
- Additional bin boundaries
    - Same approach as for between-bin uncertainties
    - Centralised calculation possible
    - Only captures acceptance effect across (conveniently placed) boundaries
- Within-STXS bin scale variations
    - Analysts ensure inclusive STXS bin cross section remains invariant
    - Does not necessarily encapsulate all relevant effects
- These uncertainties should be **small**
    - Does not mean “negligible”!