H$\rightarrow \tau\tau$ differential XS measurement overview

IOP-HEPP conference 2024

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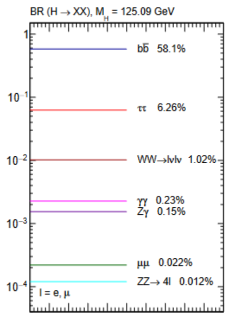
Introduction

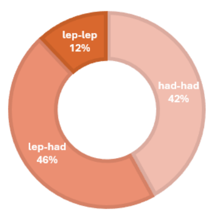
Introduction

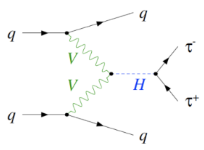
Why looking at the H→ $\tau\tau$ decay channel?

- ➔ The H→ $\tau\tau$ has the highest branching ratio to leptons, BR(H→ $\tau\tau$) ≈ 6.3%
- ➔ Fermionic decay modes provide direct measurements of the Yukawa coupling



Higgs Branching Ratio (arXiv:1610.07922)



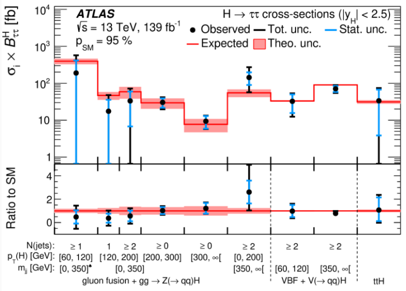


- ➔ The τ lepton is the only lepton heavy enough to allow hadronic decays (65%)
- ➔ The H→ $\tau\tau$ has a relative low background ⇒ Main background: Z→ $\tau\tau$

STXS and Differential Cross section

→ Based on a previous analysis (link):

- The pp $\rightarrow$ H $\rightarrow \tau\tau$ total cross-section and per production mode (ggF, VBF, ttH, VH) were measured
- An STXS measurement in ggF was done which focuses on the p_T^H distribution



Production mode	SM prediction [pb]	Result[pb]
$t\bar{t}H$	0.0313 ± 0.0032	0.033 ± 0.037
VH	0.1176 ± 0.0025	0.115 ± 0.070
ggF	2.77 ± 0.09	2.65 ± 0.85
VBF	0.222 ± 0.005	0.197 ± 0.041
$pp \rightarrow H$	3.17 ± 0.09	2.94 ± 0.41

→ All measurements are in agreement with the SM prediction

$\sigma_H \times$ BR(H$\rightarrow \tau\tau$) relative to the SM expectations in the 9 fiducial volumes defined in the STXS measurement (ArXiv:2201.08269)

One of the main goal for the second round analysis:

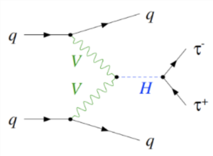
- Make the first H $\rightarrow \tau\tau$ fiducial differential measurement in ATLAS in the VBF phase space

Analysis strategy

Variables choice

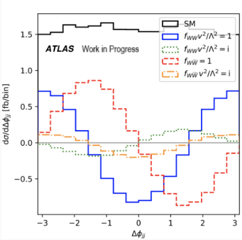
➔ Use the **VBF production mode** to study:

- ✴ The Kinematics of Higgs boson
- ✴ The CP properties of Higgs boson
- ✴ Search for new Physics using an EFT

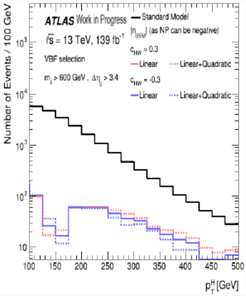


Variables to unfold: $\Delta\phi_{jj}^{signed}$, p_T^H, $p_T^{j_0}$, $\Delta\phi_{jj}^{signed}$ vs p_T^H

➔ Unfolded distributions will be used for **SMEFT interpretations**



$\Delta\phi_{jj}^{signed}$ in different EFT scenarios (ArXiv:1712.02350v1)



- ✴ $\Delta\phi_{jj}$ CP sensitive to the Higgs Gauge coupling
- ✴ Good sensitivity to possible BSM effects for p_T^H and $\Delta\phi_{jj}$ at high-p_T^H value

Fiducial region

➔ With the full Run 2 data, we can study the first differential distributions targeting VBF with $H \to \tau\tau$

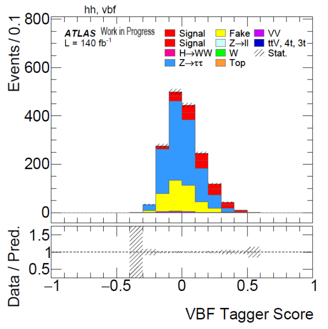
➔ Use of VBF Selection cuts + MVA Tagger (BDT) to select VBF Higgs

➔ To increase VBF purity over the ggF contamination ⇒ tight VBF cuts

➔ Two regions are defined:

- ✳ vbf_1: A region with more Signal (high BDT-score)
- ✳ vbf_0: A region with more ggF (low BDT-score)

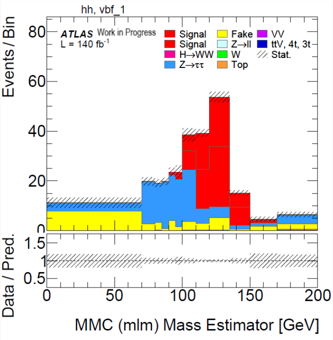
Channel	$\tau_{had}\tau_{had}$
Object counting	nb of e/μ = 0, nb of τ_{truth} = 2
p_T cut	τ_{truth}: p_T > 40, 30 GeV
Angular	ΔR < 2.5, $\lvert\eta\rvert$ < 1.5
Coll. app. x_1/x_2	0.1 < x_1 < 1.4, 0.1 < x_2 < 1.4
Jet requirements	leading jet p_T > 40 GeV sub-leading jet p_T > 30 GeV E_T^{miss} > 20 GeV Opposite charge of τ-decay products m_{jj} > 600 GeV, $\lvert\Delta\eta_{jj}\rvert$ > 3.4, p_T^{jj} > 30 GeV $\eta(j_0) \times \eta(j_1) < 0$ lepton centrality p_T^{tot} < 50 GeV



Mass Reconstruction

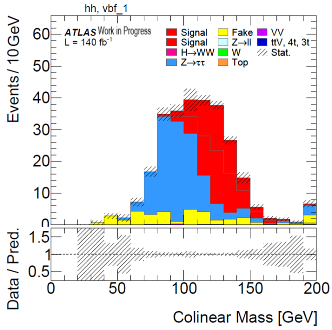
→ Goal: to fit the invariant mass of the ditau system m_{jj} in each bin of the unfolded distributions to separate signal from the dominant $Z \rightarrow \tau\tau$ background contribution

→ First step: reconstructing m_{jj} with the help of two tools:



The Missing Mass Calculator (MMC)

- Advanced likelihood-based technique
- Relies on the variance of energy and position of neutrinos due to the limited resolution, and aims at estimating their energy and direction



The Collinear Mass Approximation (CLMA)

- Only for events where MMC fails
- Assuming that (a) the invisible decay products of the τ-lepton decays fly in the same direction as the visible decay products and (b) the E_T^{miss} can only correspond to neutrinos

Main background: Z$\rightarrow \tau\tau$

$Z \rightarrow \tau\tau$ and the embedding process

1

$Z \rightarrow ll$ evt. selection
Reco. prompt light leptons

unfold e/μ reco. & trig. eff.

$Z \rightarrow ll$ full phase space
'truth leptons'

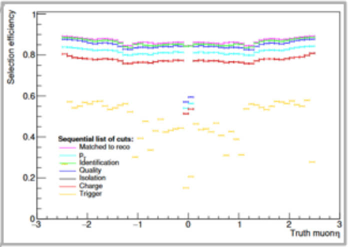
tau energy & reco. correction

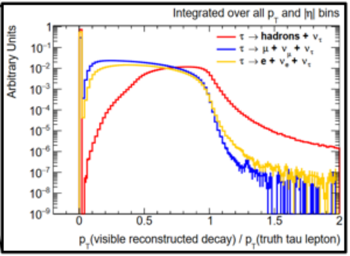
$Z \rightarrow \tau\tau$ full phase space
'reco. taus'

2

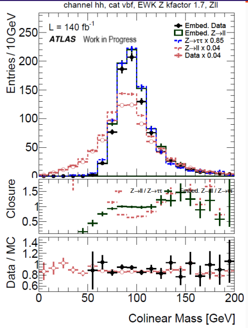
fold trigger eff. & apply SR selection

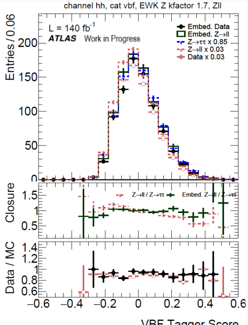
$Z \rightarrow \tau\tau$ SR selection
'reco. taus'



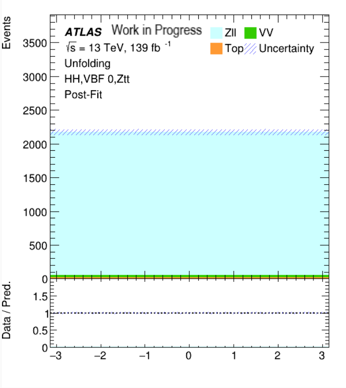


$Z \rightarrow \tau\tau$ and the embedding process





- ➔ The Z→ ll is estimated by the embedding process
- ➔ The full Z+jets normalization comes from the embedding but MC is used to model the m_{jj}^{MMC} distribution etc.



- ➔ It gives us the estimation of the Z→ll background in the Signal regions, but also gives us a norm who will be used as a Z→ll control region

Fit setup and current results

Unfolding theory

We want to measure the fiducial cross section

➔ The fiducial volume was obtained by applying cuts to particle-level events to reproduce the phase space of the measurement

The differential cross-section measurement is obtained by:

$$\sigma^{diff} = \frac{N_i^{truth}}{L} = \frac{1}{L}\frac{1}{\epsilon_i} \cdot \Sigma_j M_{ij}^{-1} \cdot f_j^{reco} \cdot (N_j^{reco} - N_j^{bgk})$$

$\epsilon_i = \frac{N_i^{truth+reco}}{N_i^{truth}}$ Efficiency

Migration Matrix

Correction Factor $f_j^{reco} = \frac{N_j^{reco+truth}}{N_j^{reco}}$

➔ Unfolding method is used to invert the migration matrix and extract the particle-level spectrum of a variable from the reconstructed

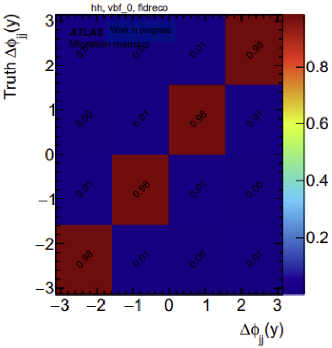
➔ Use likelihood-based unfolding that is used ⇒ The unfolding problem becomes an 'simple' matrix inversion problem

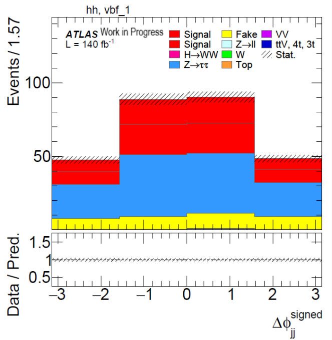
Unfolding binning

→ Limited statistics → only 4 bins for each one of the unfolding variables

→ Large off-diagonal elements lead to instabilities/large uncertanties → Choose binning in a way that the migration matrix is diagonal and easy to invert

height	$\Delta\phi_{jj}^{signed}$	p_T^H	p_T^{j0}	$\Delta\phi_{jj}^{signed}$ vs p_T^H
Bin 1	[$-\pi$, $-\pi/2$]	[0, 110] GeV	[40, 95] GeV	[p_T^H < 200 & $\Delta\phi_{jj}$ < 0]
Bin 2	[$-\pi/2$, 0]	[110, 150] GeV	[95, 130] GeV	[p_T^H < 200 & $\Delta\phi_{jj}$ > 0]
Bin 3	[0, $\pi/2$]	[150, 200] GeV	[130, 180] GeV	[p_T^H > 200 & $\Delta\phi_{jj}$ < 0]
Bin 4	[$\pi/2$, π]	[200, 550] GeV	[180, 500] GeV	[p_T^H > 200 & $\Delta\phi_{jj}$ > 0]





Asimov Fit Setup

➔ Fit the $m_{\tau\tau}^{MMC}$ in each one of the unfolded bins, with $m_{\tau\tau}^{MMC}$ ranges [0,200] GeV

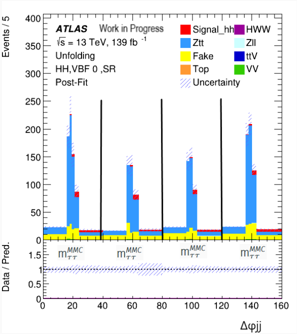
✳ 2 **signal regions** are defined; vbf_0: low-BDT score region and vbf_1: high-BDT score region

✳ **$Z\rightarrow \tau\tau$+jets control regions**; vbf_0: low-BDT score region and vbf_1: high-BDT score region

➔ Results are dominated Data stat. followed by MC stat. (Background Templates) which includes statistical uncertainty of Fake estimate and $Z\rightarrow \tau\tau$

➔ Fake Background use more inclusive template to minimize the uncertainty

➔ For $Z\rightarrow \tau\tau$ background, a morphing method is under study (see Roxani's talk)



	$\Delta\mu_{bin_1}$	$\Delta\mu_{bin_2}$	$\Delta\mu_{bin_3}$	$\Delta\mu_{bin_4}$
bins	[-π, -π/2]	[-π/2, 0]	[0, π/2]	[π/2, π]
syst+stat	± 0.52	± 0.36	± 0.34	± 0.52
stat	± 0.44	± 0.28	± 0.29	± 0.42
data stat	± 0.38	± 0.26	± 0.27	± 0.38

Conclusion

Summary

- An overview of the first differential cross-section H$\rightarrow \tau\tau$ measurement in the VBF phase space
- Four different distributions have been unfolded in this analysis: $\Delta\phi_{jj}^{signed}$, p_T^H, $p_T^{j_0}$, $\Delta\phi_{jj}^{signed}$ vs p_T^H
- We have the full results for the Asimov unfolding for the $\tau_{lep}\tau_{lep}$, $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$ channels as well as a combined fit result

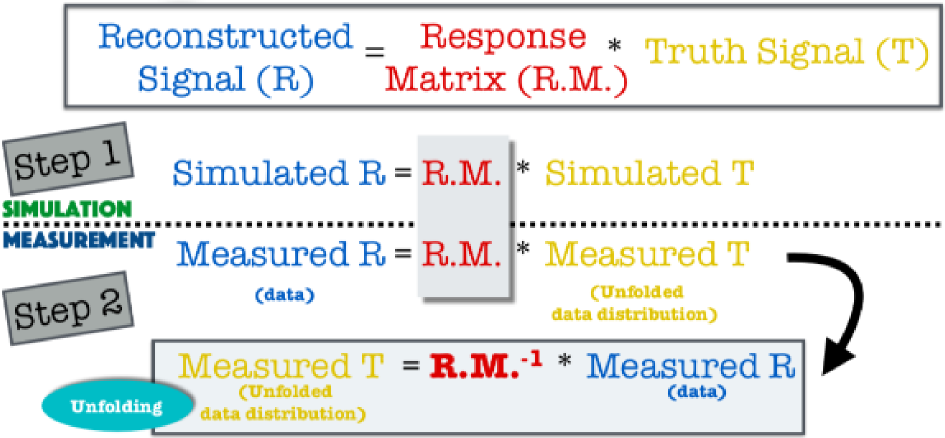
What is next for this analysis?

- Unblinding has been approved last week!

Final results coming soon!!!

Thank you for listening!

Inverting the matrix



Reconstucted signal: Detector Level Distribution

Truth signal: True distribution

Response matrix: Reconstructed observable correlated to truth observable

Event selection

- Follow the previous coupling analysis closely:
  - Use the same VBF Tagger as previous analysis
    - Only two region are defined: the low and high-BDT score, named as vbf_0 and vbf_1, respectively (same threshold as previous analysis). Only use the VBF tagger to define categories on reco level
  - To increase VBF purity over the ggH contamination ⇒ tightened VBF cuts over inclusive STXS region definition
    - The additional cuts on VBF properties are chosen to keep vbf_1 region the same and vbf_0 is reduced

Kinematic variable	Old cuts	New cuts
Pseudorapidity	$\eta^{j_0} \times \eta^{j_1} < 0$	
Pseudorapidity	$\lvert\Delta\eta_{jj}\rvert > 3.0$	$\lvert\Delta\eta_{jj}\rvert > 3.4$
Dijet-centrality	C = 1	
Invariant mass	$m_{jj} > 350$ GeV	$m_{jj} > 600$ GeV
Transverse momentum	$p_T^{j_1} > 30$ GeV	
Transverse momentum	-	$p_T^{jj} > 30$ GeV
Transverse momentum	-	$p_T^{tot} < 50$ GeV

- On truth level, we used the same VBF selection cuts as on reco level
- On truth level, the ggH contamination is reduced 28.7% → 16.6%

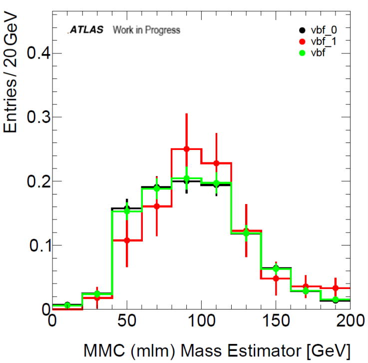
Fiducial region

- With the full Run 2 data, we can study the first differential distributions targeting VBF with H→ $\tau\tau$
- The fiducial region is defined to be as close as possible to the detector level VBF selection, and with a high VBF purity
- The 3 decay channels have different kinematic cuts on Higgs decay products, while jet requirements are unified

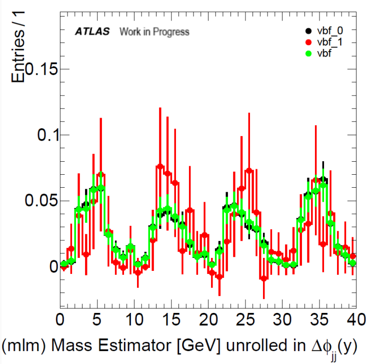
Channel	$\tau_e\tau_\mu$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$
Object counting	nb of e = 1, nb of μ = 1, nb of τ_{truth} = 0	nb of e/μ = 1, nb of τ_{truth} = 1	nb of e/μ = 0, nb of τ_{truth} = 2
p_T cut	e/μ : p_T cut 10 to 27.3 GeV	e/μ : pT cut 27.0 to 27.3 GeV τ_{truth}: p_T > 30 GeV	τ_{truth}: p_T > 40, 30 GeV
Kinematics	$m_{\tau\tau}^{coll} > m_{Z-}$ 25GeV 30 < m_e < 100 GeV	m_τ < 70 GeV	
Angular	$\Delta R_{e\mu} < 2.0$, $\lvert\eta_{e\mu}\rvert < 1.5$	$\Delta R_l < 2.5$, $\lvert\eta_l\rvert < 1.5$	$\Delta R < 2.5$, $\lvert\eta\rvert < 1.5$
Coll. app. x_1/x_2	$0.1 < x_1 < 1.0$, $0.1 < x_2 < 1.0$	$0.1 < x_1 < 1.4$, $0.1 < x_2 < 1.2$	$0.1 < x_1 < 1.4$, $0.1 < x_2 < 1.4$
	leading jet p_T > 40 GeV, sub-leading jet p_T > 30 GeV E_T^{miss} > 20 GeV Opposite charge of τ-decay products m_{jj} > 600 GeV, $\lvert\Delta\eta_{jj}\rvert$ > 3.4, p_T^{jj} > 30 GeV $\eta(j_0) \times \eta(j_1) < 0$ lepton centrality: visible decay products of the τ leptons between VBF jets p_T^{tot} < 50 GeV		

Shape plot for fakes

- We want to study the shape of the fakes distribution for each bins in the mass distribution unfolded in $\Delta\phi_{jj}$ to see if we can use a more inclusive shape template in the different bins of $\Delta\phi_{jj}$

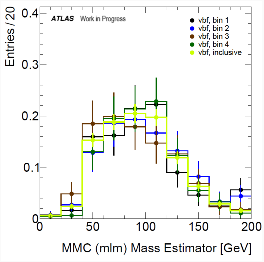


Standard

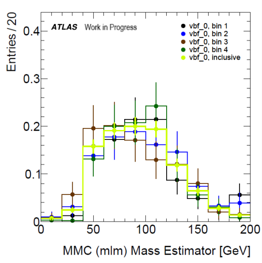


Unrolled

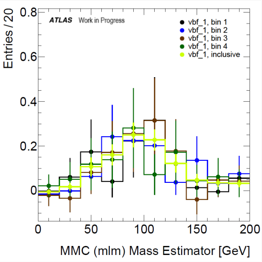
Shape plot for fakes



VBF inclusive



VBF 0



VBF 1

- We choose to use the inclusive shape of the fakes for each bin in signed $\Delta\phi_{jj}$ and $\Delta\phi_{jj}$ vs p_T^H
- We choose to use the inclusive shape of the fakes for total distribution in p_T^H and $p_T^{j_0}$
- As the $\Delta\phi_{jj}^{signed}$ and p_T^H vs $\Delta\phi_{jj}^{signed}$ unfolded distributions have a symmetry around 0, we make the average between the background of two bins to increase our data and stats
- Those templates don't improve our results neither they make them worse but they increase the stability of our fit

$\Delta\phi_{jj}^{signed}$

	bins	$\Delta\mu_{bin_1}$ [-π, -π/2]	$\Delta\mu_{bin_2}$ [-π/2, 0]	$\Delta\mu_{bin_3}$ [0, π/2]	$\Delta\mu_{bin_4}$ [π/2, π]
Combined	syst+stat	± 0.42	± 0.24	± 0.24	± 0.41
	stat	± 0.32	± 0.19	± 0.19	± 0.31
	data stat	± 0.28	± 0.17	± 0.17	± 0.28
$\tau_{lep}\tau_{had}$	syst+stat	± 0.63	± 0.35	± 0.35	± 0.64
	stat	± 0.54	± 0.32	± 0.32	± 0.54
	data stat	± 0.46	± 0.25	± 0.25	± 0.46
$\tau_{had}\tau_{had}$	syst+stat	± 0.52	± 0.36	± 0.34	± 0.52
	stat	± 0.44	± 0.28	± 0.29	± 0.42
	data stat	± 0.38	± 0.26	± 0.27	± 0.38
$\tau_e\tau_\mu$	syst+stat	± 1.78	± 0.89	± 0.88	± 1.77
	stat	± 1.50	± 0.74	± 0.74	± 1.50
	data stat	± 1.26	± 0.65	± 0.64	± 1.26

⇒ Uncertainty on μ for each of the bins of the $\Delta\phi_{jj}$ distribution for combined fit and the $\tau_{lep}\tau_{had}$, $\tau_{had}\tau_{had}$, and $\tau_e\tau_\mu$ channel fits.“stat” included Data and MC statistics, while “data stat” only includes data statistics

⇒ Those results are taken from the internal notes → Update will come soon with the Z→ $\tau\tau$ modelling uncertainties and the signal theory uncertainties added → Results will be slightly worse

⇒ Data stat. has the largest contribution followed by MC stat

p_T^H

	bins [GeV]	$\Delta\mu_{bin_1}$ [0, 110]	$\Delta\mu_{bin_2}$ [110, 150]	$\Delta\mu_{bin_3}$ [150, 200]	$\Delta\mu_{bin_4}$ [200, 550]
Combined	syst+stat	$\pm$ 0.78	$\pm$ 0.50	$\pm$ 0.38	$\pm$ 0.23
	stat	$\pm$ 0.49	$\pm$ 0.39	$\pm$ 0.30	$\pm$ 0.19
	data stat	$\pm$ 0.39	$\pm$ 0.31	$\pm$ 0.24	$\pm$ 0.16
$\tau_{lep}\tau_{had}$	syst+stat	$\pm$ 0.92	$\pm$ 0.67	$\pm$ 0.53	$\pm$ 0.37
	stat	$\pm$ 0.67	$\pm$ 0.59	$\pm$ 0.47	$\pm$ 0.34
	data stat	$\pm$ 0.62	$\pm$ 0.45	$\pm$ 0.37	$\pm$ 0.25
$\tau_{had}\tau_{had}$	syst+stat	$\pm$ 1.07	$\pm$ 0.75	$\pm$ 0.47	$\pm$ 0.30
	stat	$\pm$ 0.83	$\pm$ 0.61	$\pm$ 0.39	$\pm$ 0.26
	data stat	$\pm$ 0.66	$\pm$ 0.48	$\pm$ 0.32	$\pm$ 0.22
$\tau_e\tau_\mu$	syst+stat	$\pm$ 4.08	$\pm$ 1.51	$\pm$ 1.75	$\pm$ 1.44
	stat	$\pm$ 2.57	$\pm$ 1.28	$\pm$ 1.28	$\pm$ 1.11
	data stat	$\pm$ 1.99	$\pm$ 0.98	$\pm$ 0.98	$\pm$ 0.83

$\Rightarrow$ Uncertainty on μ for each of the bins of the p_T^H distribution for combined fit and the $\tau_{lep}\tau_{had}$, $\tau_{had}\tau_{had}$, and $\tau_e\tau_\mu$ channel fits."stat" included Data and MC statistics, while "data stat" only includes data statistics

$\Rightarrow$ Those results are taken from the internal notes $\rightarrow$ Update will come soon with the $Z\rightarrow\tau\tau$ modelling uncertainties and the signal theory uncertainties added $\rightarrow$ Results will be slightly worse

$\Rightarrow$ Data stat. has the largest contribution followed by MC stat

$p_T^{j_0}$

	bins [GeV]	$\Delta\mu_{bin_1}$ [40, 95]	$\Delta\mu_{bin_2}$ [95, 130]	$\Delta\mu_{bin_3}$ [130, 180]	$\Delta\mu_{bin_4}$ [180, 500]
Combined	syst+stat	$\pm$ 0.53	$\pm$ 0.47	$\pm$ 0.37	$\pm$ 0.30
	stat	$\pm$ 0.39	$\pm$ 0.36	$\pm$ 0.32	$\pm$ 0.24
	data stat	$\pm$ 0.32	$\pm$ 0.30	$\pm$ 0.27	$\pm$ 0.20
$\tau_{lep}\tau_{had}$	syst+stat	$\pm$ 0.67	$\pm$ 0.62	$\pm$ 0.59	$\pm$ 0.46
	stat	$\pm$ 0.53	$\pm$ 0.60	$\pm$ 0.57	$\pm$ 0.44
	data stat	$\pm$ 0.44	$\pm$ 0.44	$\pm$ 0.42	$\pm$ 0.33
$\tau_{had}\tau_{had}$	syst+stat	$\pm$ 1.00	$\pm$ 0.63	$\pm$ 0.50	$\pm$ 0.41
	stat	$\pm$ 0.82	$\pm$ 0.55	$\pm$ 0.44	$\pm$ 0.33
	data stat	$\pm$ 0.65	$\pm$ 0.45	$\pm$ 0.37	$\pm$ 0.28
$\tau_e\tau_\mu$	syst+stat	$\pm$ 2.23	$\pm$ 1.94	$\pm$ 1.83	$\pm$ 1.65
	stat	$\pm$ 1.64	$\pm$ 1.61	$\pm$ 1.60	$\pm$ 1.33
	data stat	$\pm$ 1.25	$\pm$ 1.21	$\pm$ 1.18	$\pm$ 0.99

$\Rightarrow$ Uncertainty on μ for each of the bins of the $p_T^{j_0}$ distribution for combined fit and the $\tau_{lep}\tau_{had}$, $\tau_{had}\tau_{had}$, and $\tau_e\tau_\mu$ channel fits."stat" included Data and MC statistics, while "data stat" only includes data statistics

$\Rightarrow$ Those results are taken from the internal notes $\rightarrow$ Update will come soon with the $Z\rightarrow\tau\tau$ modelling uncertainties and the signal theory uncertainties added $\rightarrow$ Results will be slightly worse

$\Rightarrow$ Data stat. has the largest contribution followed by MC stat

$\Delta\phi_{jj}^{signed}$ vs p_T^H

	bins bins [GeV]	$\Delta\mu_{bin_1}$ < 0 < 200	$\Delta\mu_{bin_2}$ > 0 < 200	$\Delta\mu_{bin_3}$ < 0 > 200	$\Delta\mu_{bin_4}$ > 0 > 200
Combined	syst+stat	± 0.29	± 0.28	± 0.32	± 0.32
	stat	± 0.23	± 0.22	± 0.28	± 0.29
	data stat	± 0.20	± 0.20	± 0.25	± 0.25
$\tau_{lep}\tau_{had}$	syst+stat	± 0.43	± 0.42	± 0.52	± 0.52
	stat	± 0.37	± 0.34	± 0.49	± 0.49
	data stat	± 0.32	± 0.31	± 0.37	± 0.38
$\tau_{had}\tau_{had}$	syst+stat	± 0.41	± 0.39	± 0.47	± 0.49
	stat	± 0.34	± 0.33	± 0.40	± 0.41
	data stat	± 0.31	± 0.30	± 0.35	± 0.36
$\tau_e\tau_\mu$	syst+stat	± 1.12	± 1.10	± 1.63	± 1.66
	stat	± 0.85	± 0.83	± 1.42	± 1.44
	data stat	± 0.73	± 0.72	± 1.19	± 1.21

$\Rightarrow$ Uncertainty on μ for each of the bins of the $\Delta\phi_{jj}$ vs p_T^H distribution for combined fit and the $\tau_{lep}\tau_{had}$, $\tau_{had}\tau_{had}$, and $\tau_e\tau_\mu$ channel fits.“stat” included Data and MC statistics, while “data stat” only includes data statistics

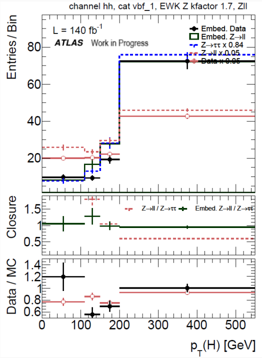
$\Rightarrow$ Those results are taken from the internal notes $\rightarrow$ Update will come soon with the Z$\rightarrow \tau\tau$ modelling uncertainties and the signal theory uncertainties added $\rightarrow$ Results will be slightly worse

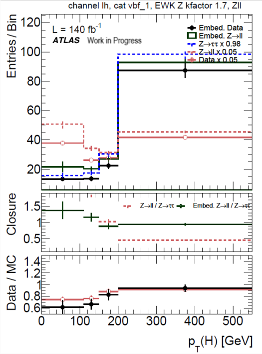
$\Rightarrow$ Data stat. has the largest contribution followed by MC stat

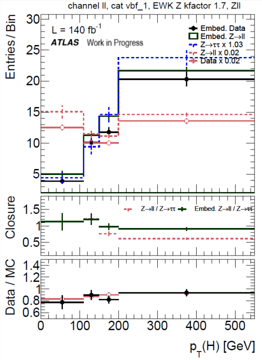
Background Template

Background estimation: Z$\rightarrow \tau\tau$

- The Z$\rightarrow \tau\tau$ process, as in the previous analysis, has been estimated through the **object-level embedding procedure**
- The full Z+jets normalization comes from the embedding but MC is used to model the m_{MMC} distribution and the distributions under study







Grouped impact of systematics for $\Delta\phi_{jj}$

POI bins	μ_{Bin1} $[-\pi, -\pi/2]$	μ_{Bin2} $[-\pi/2, 0]$	μ_{Bin3} $[0, \pi/2]$	μ_{Bin4} $[\pi/2, \pi]$
best-fit	1.000	1.000	1.000	1.000
Full Unc	±0.365	±0.210	±0.210	±0.359
stat only	±0.284	±0.171	±0.172	±0.281
full syst	±0.233	±0.125	±0.124	±0.227
MC stat	±0.153	±0.077	±0.077	±0.149
Sig theory				
Jet + Met	±0.120	±0.074	±0.068	±0.114
Tau	±0.058	±0.035	±0.036	±0.061
Fake	±0.104	±0.041	±0.044	±0.227
Lumi	±0.002	±0.001	±0.001	±0.002
Top theory	±0.018	±0.022	±0.019	±0.017
Z theory	±0.026	±0.009	±0.008	±0.026
B-jet	±0.004	±0.003	±0.004	±0.004
Lepton	±0.023	±0.019	±0.019	±0.022
NormFactors	±0.061	±0.047	±0.044	±0.058

Grouped impact of different systematic sources for each of the bins of the $\Delta\phi_{jj}$ distribution for the combined Asimov fit. “stat only” includes only data statistics.

Results for $p_T^{j_0}$ in the $H \rightarrow \tau\tau$ differential analysis

	bins [GeV]	$\Delta\mu_{\text{Bin1}}$ [40, 95]	$\Delta\mu_{\text{Bin2}}$ [95, 130]	$\Delta\mu_{\text{Bin3}}$ [130, 180]	$\Delta\mu_{\text{Bin4}}$ [180, 500]
combined	syst+stat	±0.515	±0.387	±0.352	±0.263
	stat	±0.394	±0.356	±0.322	±0.240
	data stat	±0.322	±0.297	±0.269	±0.202
$\tau_{lep}\tau_{had}$	syst+stat	±0.604	±0.616	±0.587	±0.458
	stat	±0.527	±0.597	±0.571	±0.441
	data stat	±0.444	±0.441	±0.418	±0.328
$\tau_{had}\tau_{had}$	syst+stat	±0.969	±0.591	±0.475	±0.354
	stat	±0.816	±0.546	±0.444	±0.328
	data stat	±0.648	±0.454	±0.374	±0.276
$\tau_e\tau_\mu$	syst+stat	±2.232	±1.830	±1.726	±1.447
	stat	±1.641	±1.611	±1.595	±1.333
	data stat	±1.245	±1.212	±1.182	±0.991

Grouped impact of systematics for $p_T^{j_0}$

POI bins [GeV]	μ_{Bin1} [40, 95]	μ_{Bin2} [95, 130]	μ_{Bin3} [130, 180]	μ_{Bin4} [180, 500]
best-fit	1.000	1.000	1.000	1.000
Full Unc	±0.515	±0.387	±0.352	±0.263
stat only	±0.323	±0.297	±0.269	±0.202
full syst	±0.404	±0.248	±0.229	±0.171
MC stat	±0.262	±0.199	±0.186	±0.133
Sig theory				
Jet + Met	±0.201	±0.100	±0.114	±0.068
Tau	±0.046	±0.065	±0.047	±0.051
Fake	±0.191	±0.068	±0.054	±0.020
Lumi	±0.001	±0.001	±0.001	±0.001
Top theory	±0.073	±0.049	±0.035	±0.051
Z theory	±0.030	±0.017	±0.016	±0.009
B-jet	±0.003	±0.004	±0.006	±0.003
Lepton	±0.059	±0.023	±0.022	±0.018
NormFactors	±0.136	±0.041	±0.037	±0.029

Grouped impact of different systematic sources for each of the bins of the $p_T^{j_0}$ distribution for the combined Asimov fit. “stat only” includes only data statistics.

Results for p_T^H in the H$\rightarrow \tau\tau$ differential analysis

bins [GeV]		$\Delta\mu_{\text{Bin1}}$ [0, 110]	$\Delta\mu_{\text{Bin2}}$ [110, 150]	$\Delta\mu_{\text{Bin3}}$ [150, 200]	$\Delta\mu_{\text{Bin4}}$ [200, 550]
combined	syst+stat	±0.676	±0.445	±0.345	±0.202
	stat	±0.488	±0.386	±0.301	±0.185
	data stat	±0.385	±0.305	±0.241	±0.159
$\tau_{lep}\tau_{had}$	syst+stat	±0.818	±0.622	±0.507	±0.352
	stat	±0.672	±0.591	±0.466	±0.340
	data stat	±0.623	±0.451	±0.374	±0.249
$\tau_{had}\tau_{had}$	syst+stat	±1.015	±0.707	±0.445	±0.285
	stat	±0.828	±0.613	±0.390	±0.257
	data stat	±0.656	±0.483	±0.319	±0.220
$\tau_e\tau_\mu$	syst+stat	±3.906	±1.514	±1.616	±1.347
	stat	±2.570	±1.277	±1.282	±1.110
	data stat	±1.990	±0.980	±0.984	±.827

Grouped impact of systematics for p_T^H

POI bins [GeV]	μ_{Bin1} [0, 110]	μ_{Bin2} [110, 150]	μ_{Bin3} [150, 200]	μ_{Bin4} [200, 550]
best-fit	1.000	1.000	1.000	1.000
Full Unc	±0.676	±0.445	±0.345	±0.202
stat only	±0.385	±0.305	±0.241	±0.159
full syst	±0.559	±0.327	±0.250	±0.126
MC stat	±0.346	±0.253	±0.191	±0.096
Sig theory				
Jet + Met	±0.197	±0.166	±0.131	±0.061
Tau	±0.122	±0.054	±0.082	±0.042
Fake	±0.363	±0.116	±0.067	±0.017
Lumi	±0.002	±0.001	±0.001	±0.001
Top theory	±0.054	±0.028	±0.027	±0.014
Z theory	±0.089	±0.024	±0.022	±0.012
B-jet	±0.004	±0.008	±0.004	±0.002
Lepton	±0.044	±0.030	±0.018	±0.008
NormFactors	±0.166	±0.104	±0.058	±0.033

Grouped impact of different systematic sources for each of the bins of the p_T^H distribution for the combined Asimov fit. “stat only” includes only data statistics.

Results for $\Delta\phi_{jj}$ vs p_T^H in the H$\rightarrow\tau\tau$ differential analysis

		$\Delta\mu_{\mathrm{Bin1}}$	$\Delta\mu_{\mathrm{Bin2}}$	$\Delta\mu_{\mathrm{Bin3}}$	$\Delta\mu_{\mathrm{Bin4}}$
bins		< 0	> 0	< 0	> 0
bins [GeV]		< 200	< 200	> 200	> 200
combined	syst+stat	±0.276	±0.270	±0.306	±0.309
	stat	±0.225	±0.221	±0.284	±0.287
	data stat	±0.202	±0.199	±0.252	±0.254
$\tau_{lep}\tau_{had}$	syst+stat	±0.408	±0.399	±0.495	±0.496
	stat	±0.368	±0.337	±0.486	±0.488
	data stat	±0.318	±0.309	±0.374	±0.375
$\tau_{had}\tau_{had}$	syst+stat	±0.394	±0.377	±0.436	±0.441
	stat	±0.342	±0.331	±0.400	±0.405
	data stat	±0.307	±0.299	±0.354	±0.358
$\tau_e\tau_\mu$	syst+stat	±1.079	±1.059	±1.545	±1.569
	stat	±0.849	±0.833	±1.417	±1.440
	data stat	±0.734	±0.721	±1.187	±1.207

Grouped impact of systematics for $\Delta\phi_{jj}$ vs p_T^H

POI	μ_{Bin1}	μ_{Bin2}	μ_{Bin3}	μ_{Bin4}
bins	< 0	> 0	< 0	> 0
bins [GeV]	< 200	< 200	> 200	> 200
best-fit	1.000	1.000	1.000	1.000
Full Unc	±0.276	±0.270	±0.306	±0.309
stat only	±0.202	±0.199	±0.252	±0.254
full syst	±0.191	±0.186	±0.178	±0.181
MC stat	±0.112	±0.108	±0.136	±0.137
Sig theory				
Jet + Met	±0.090	±0.088	±0.092	±0.093
Tau	±0.054	±0.054	±0.058	±0.059
Fake	±0.086	±0.085	±0.027	±0.027
Lumi	±0.001	±0.001	±0.001	±0.001
Top theory	±0.026	±0.024	±0.016	±0.017
Z theory	±0.007	±0.007	±0.020	±0.020
B-jet	±0.003	±0.003	±0.003	±0.003
Lepton	±0.012	±0.013	±0.022	±0.021
NormFactors	±0.068	±0.068	±0.054	±0.053

Grouped impact of different systematic sources for each of the bins of the $\Delta\phi_{jj}$ vs p_T^H distribution for the combined Asimov fit. “stat only” includes only data statistics.