

CSI Presentation

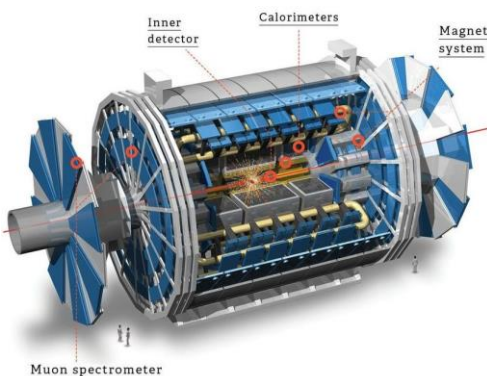
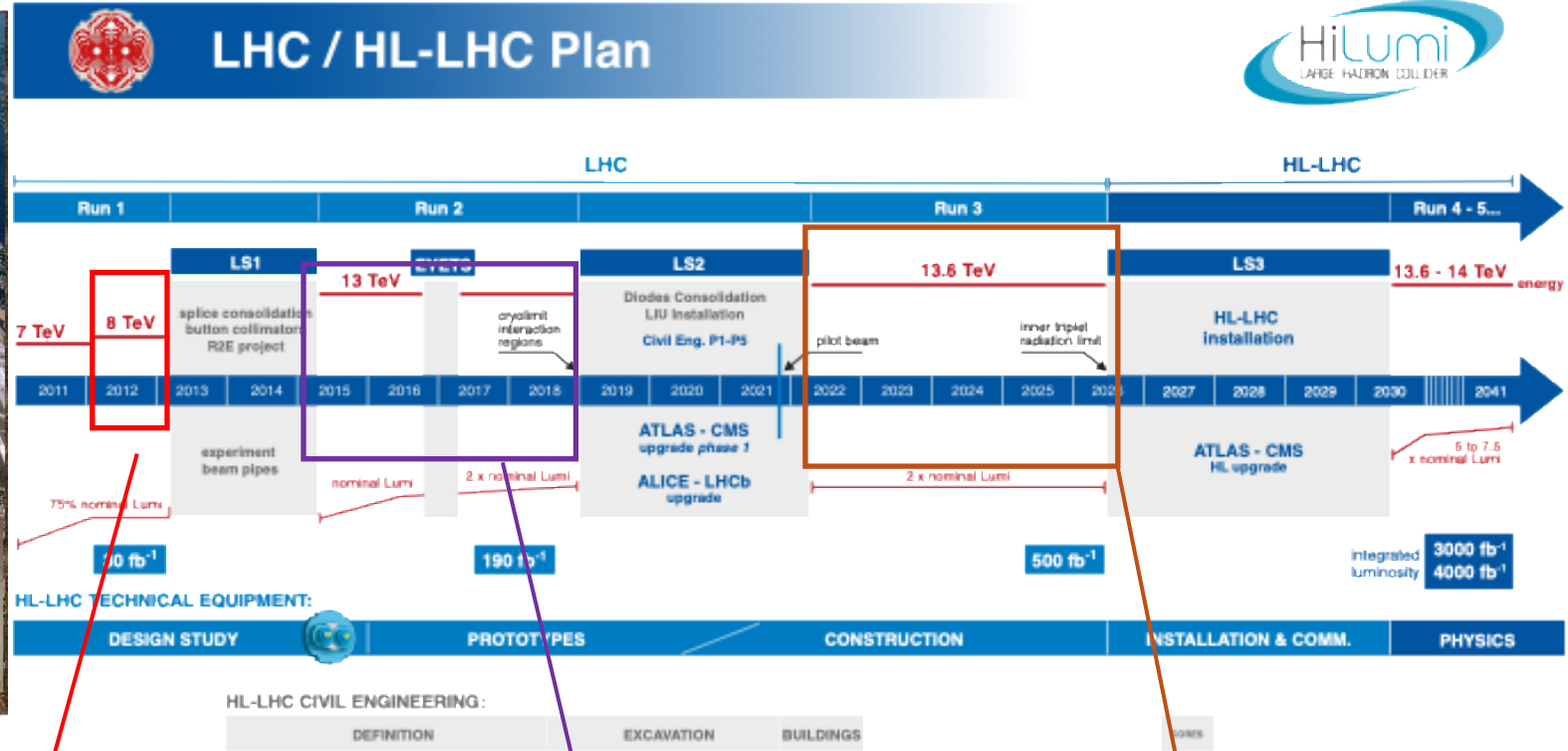
Measurement of the Vector Boson Scattering process in the $W^{\pm}Z$ channel, with the ATLAS detector at LHC

Panagiotis Ziakas



- **Introduction**
 - The VBS process
 - Why is VBS important?
 - VBS topology
- **Profile Likelihood Unfolding**
 - Definition
 - Mathematical formulation
 - Methodology
- **Differential Cross Section Measurements**
 - Run2 Inclusive Unfolding
 - Run2 Simultaneous Unfolding
- **Conclusions and next steps**
- **Doctoral School Training**

Introduction

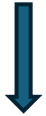


Higgs boson Discovery

Observation and precise measurements of rare processes

Deeper understanding of the existing processes & exploration of New Physics

Vector Boson Scattering (VBS)



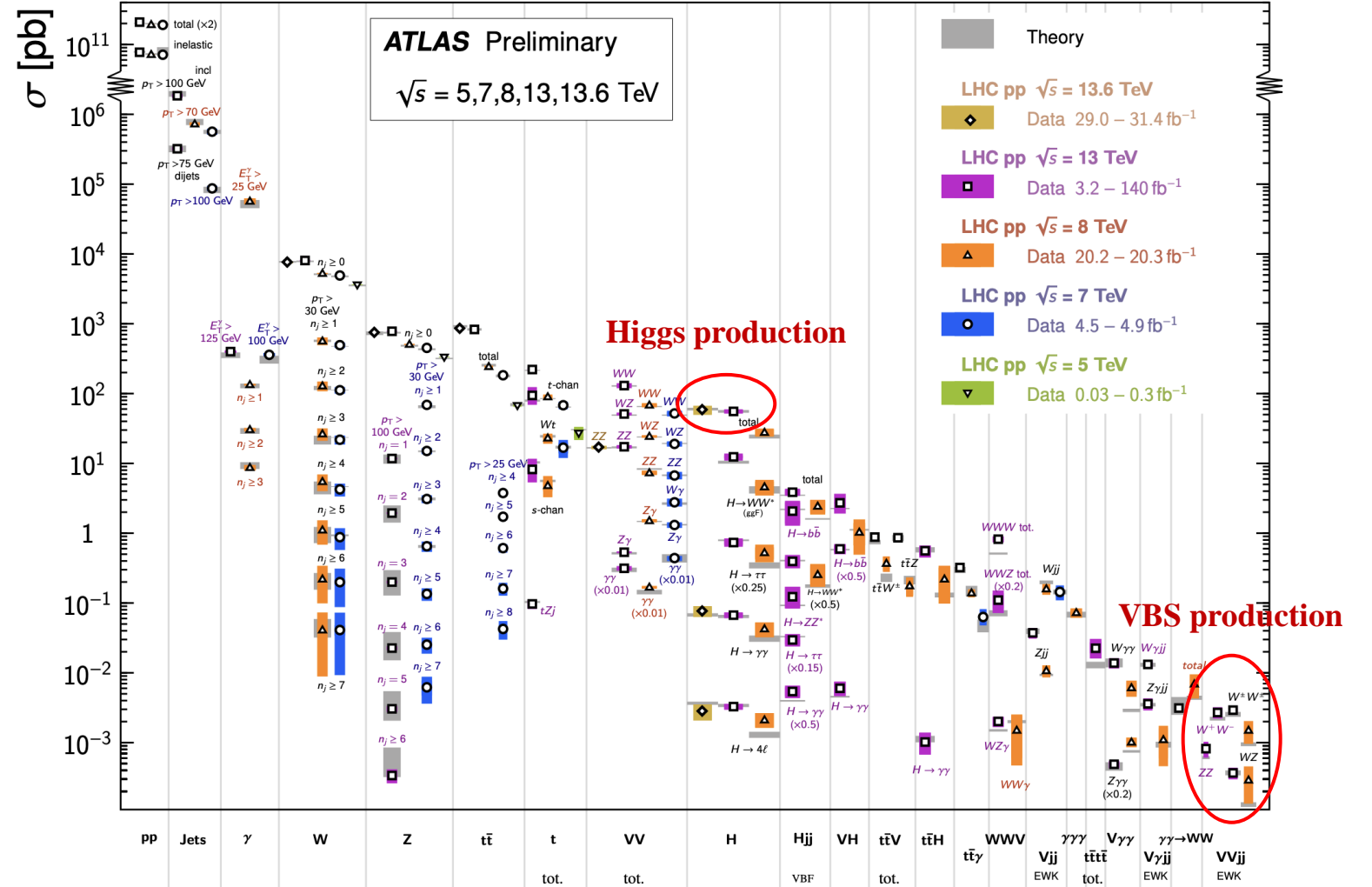
Rare but very important process!



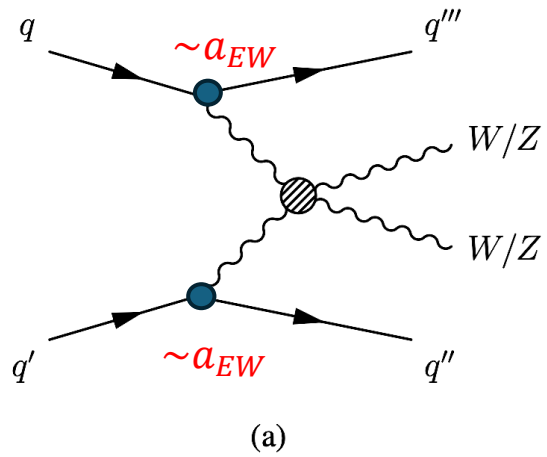
EW symmetry breaking

Vector boson self-couplings

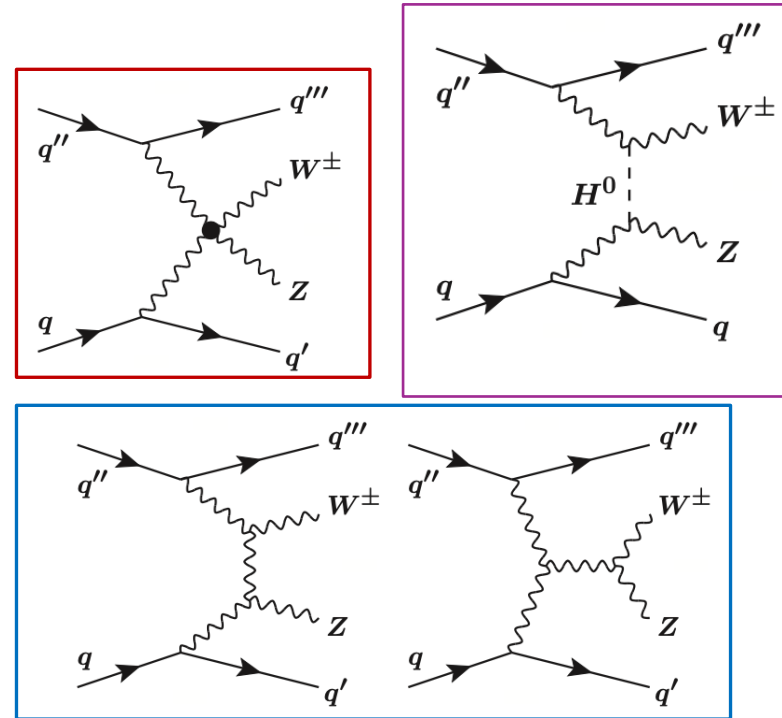
Standard Model Production Cross Section Measurements



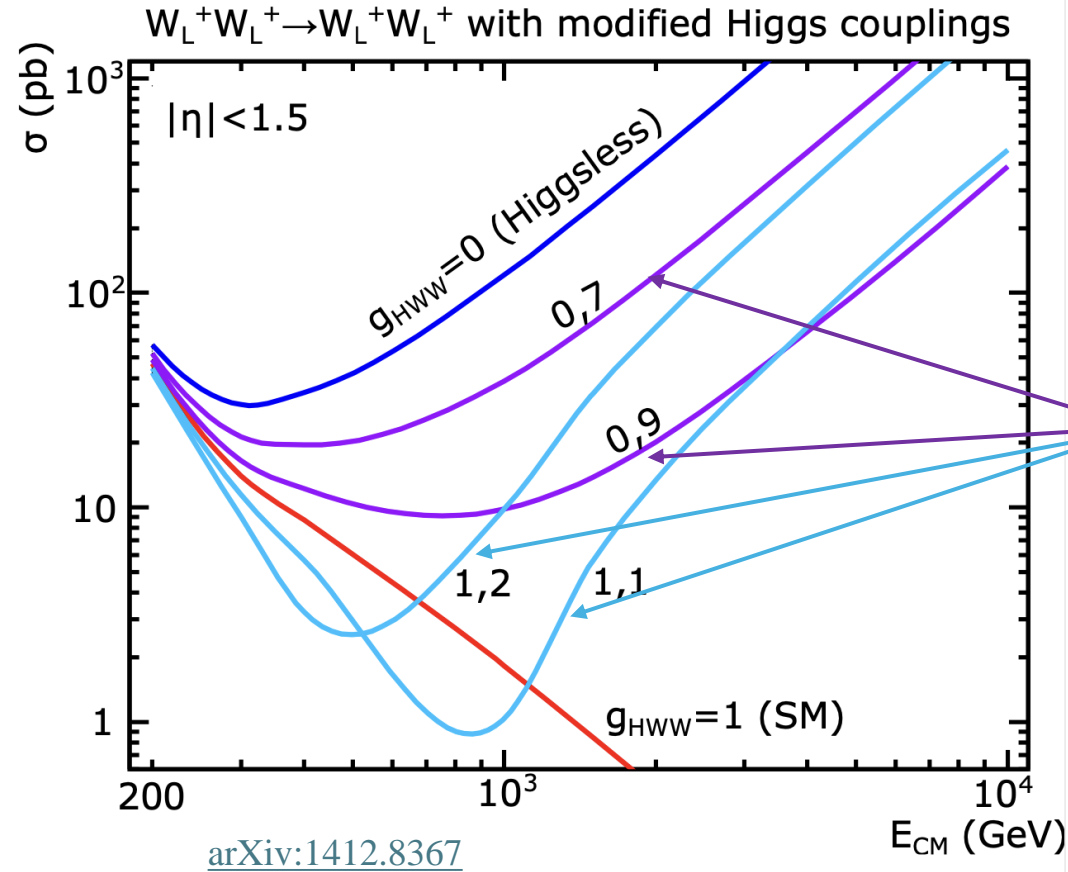
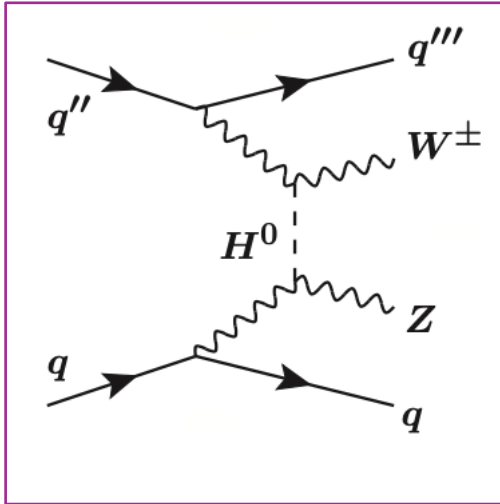
The Vector Boson Scattering process



EW VVjj via VBS

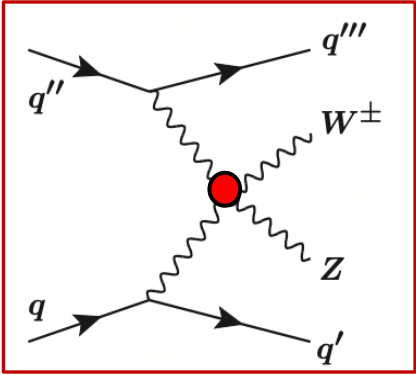


Longitudinally polarized boson production offers an excellent test of the electroweak symmetry breaking!

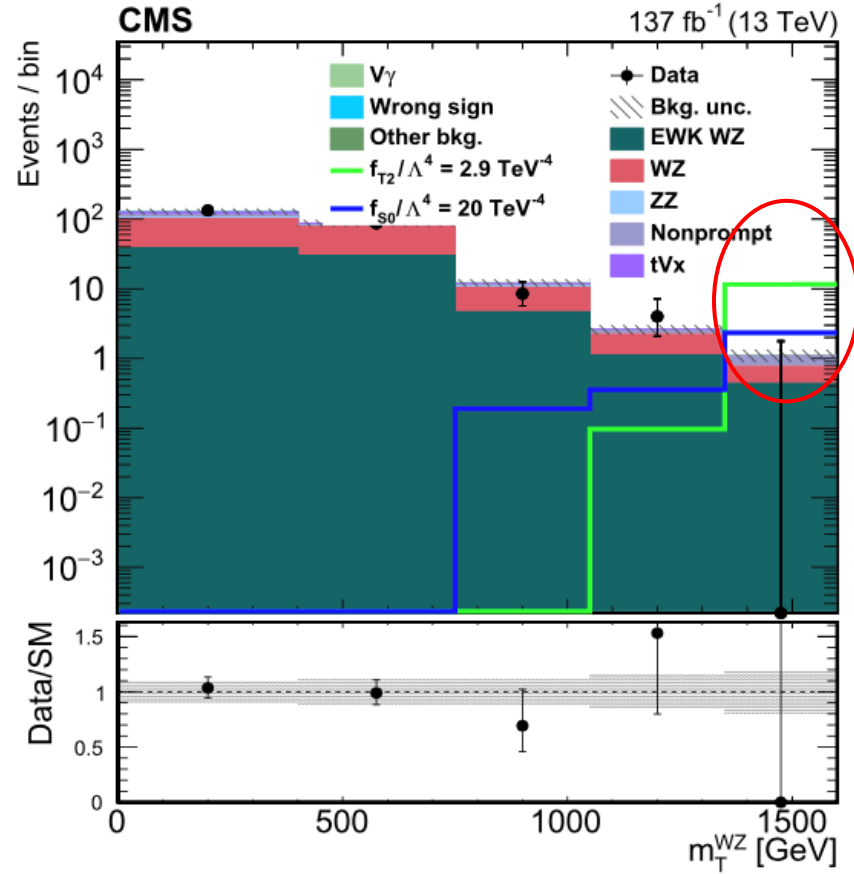


Unitarity violation if Higgs coupling deviates from SM!

Quartic Gauge Coupling measurement



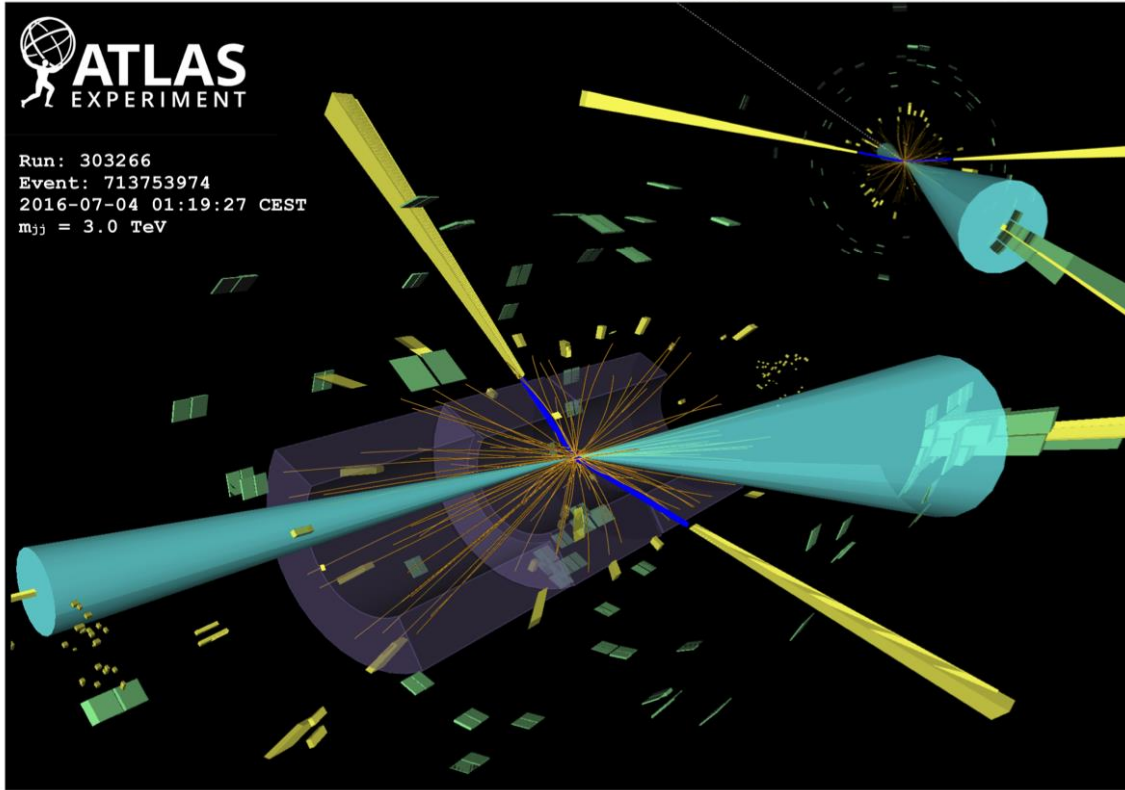
● Quartic Gauge Coupling (QGCs)



- Beyond SM theories predict enhanced couplings!
- Deviations might signal the existence of new physics!



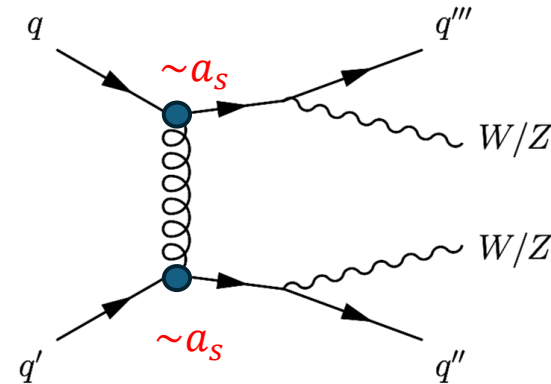
- Deviations manifest themselves as excess of events!
- Important to measure cross section differentially!



$WW \rightarrow l\nu l\nu$ event

- Two oppositely charged leptons from Z (yellow)
- One lepton and one neutrino from W (yellow)
- Two high energy forward jets (blue)
- Additional jets due to higher order effects

WZ VBS Signal Region



(c)

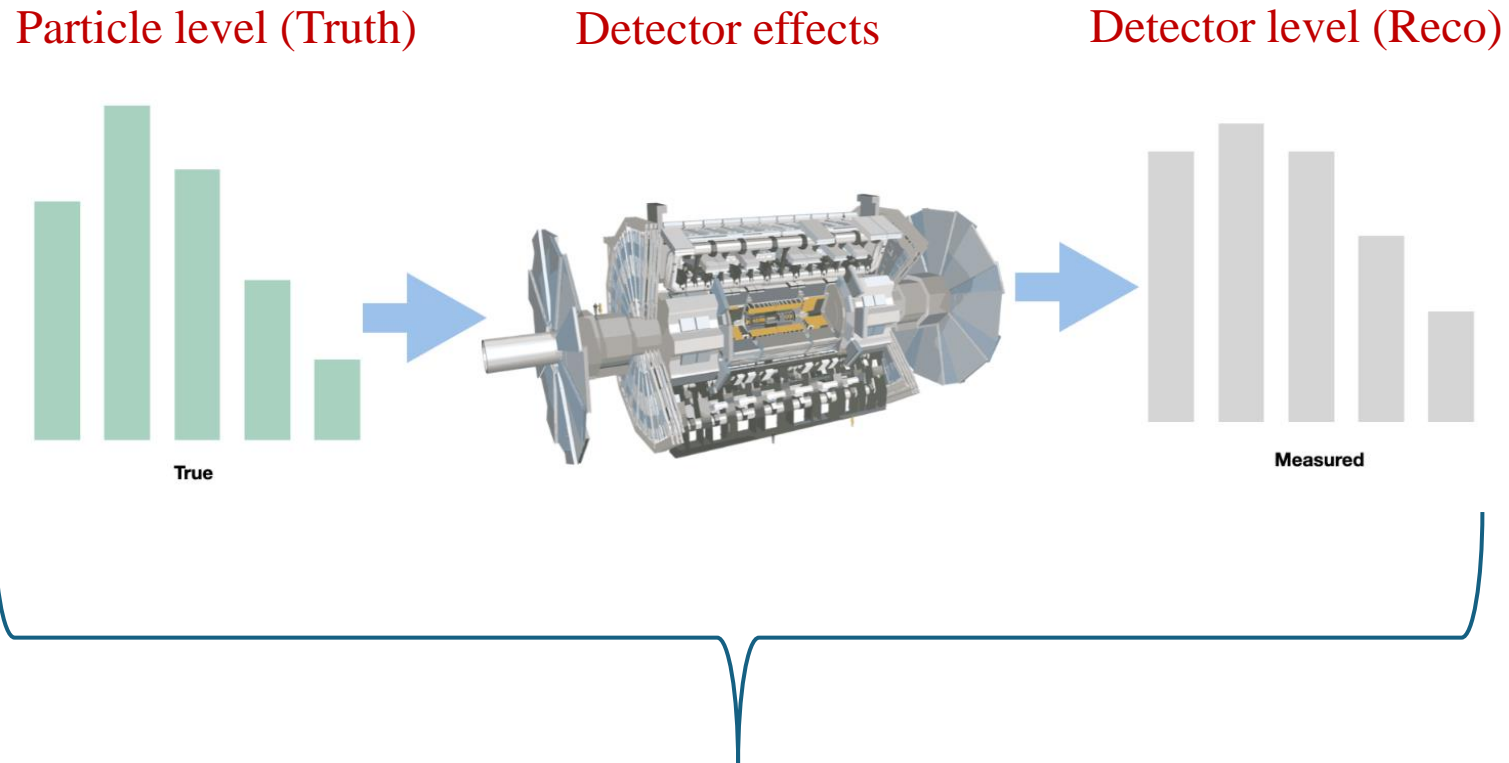
QCD VVjj

○ Major background source!

○ Fortunately, different topology!

Profile Likelihood Unfolding

The distributions of kinematic variables at Particle level are subject to distortions due to detector effects!



Unfolding: The process of correcting the detector level distributions to get a good guess of the particle level distributions

$$\nu_i = \sum_j R_{ij} \mu_j + \beta_i$$

Signal events in the $i - th$ bin of the detector level distribution

Response matrix

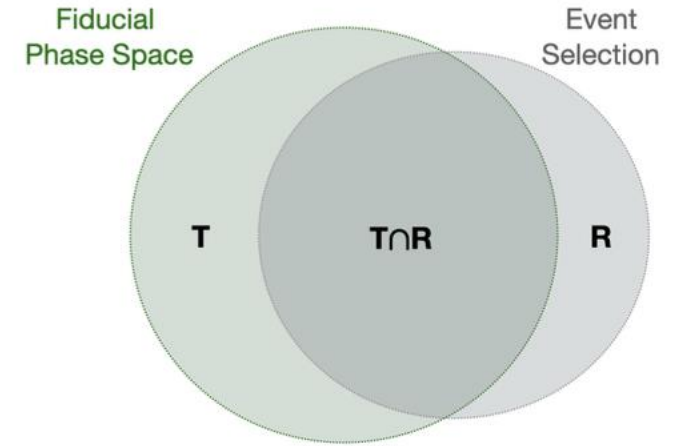
Signal events in the $j - th$ bin of the particle level distribution

Background events in the $i - th$ bin of the detector level distribution

$$\vec{\nu} = R \cdot \vec{\mu} + \vec{\beta} \quad \text{where} \quad R = \frac{1}{\vec{\alpha}} \cdot M \cdot \vec{\epsilon}$$

$$R = \frac{1}{\vec{\alpha}} \cdot M \cdot \vec{\epsilon}$$

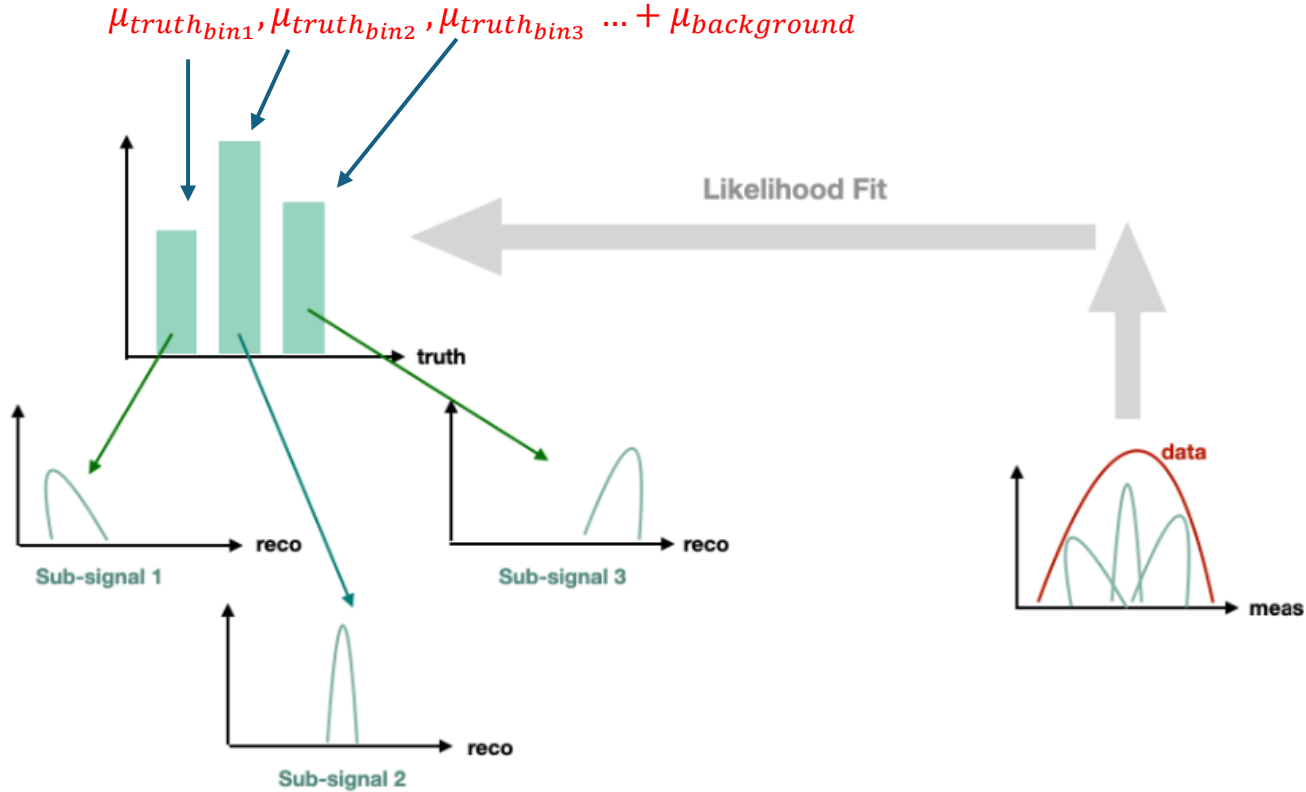
- Acceptance ($\vec{\alpha}$)
- Efficiency ($\vec{\epsilon}$)
- Migration matrix (M)



□ $\epsilon = \frac{P(R \cap T)}{P(T)} = P(R|T) \rightarrow$ Percentage of truth events that get reconstructed

□ $\alpha = \frac{P(R \cap T)}{P(R)} = P(T|R) \rightarrow$ Percentage of reconstructed events that come from actual truth events

□ $M \rightarrow$ Migration matrix that accounts for the probability of an event produced at the $i - th$ bin at Particle level, to be reconstructed in the $j - th$ bin at Detector level

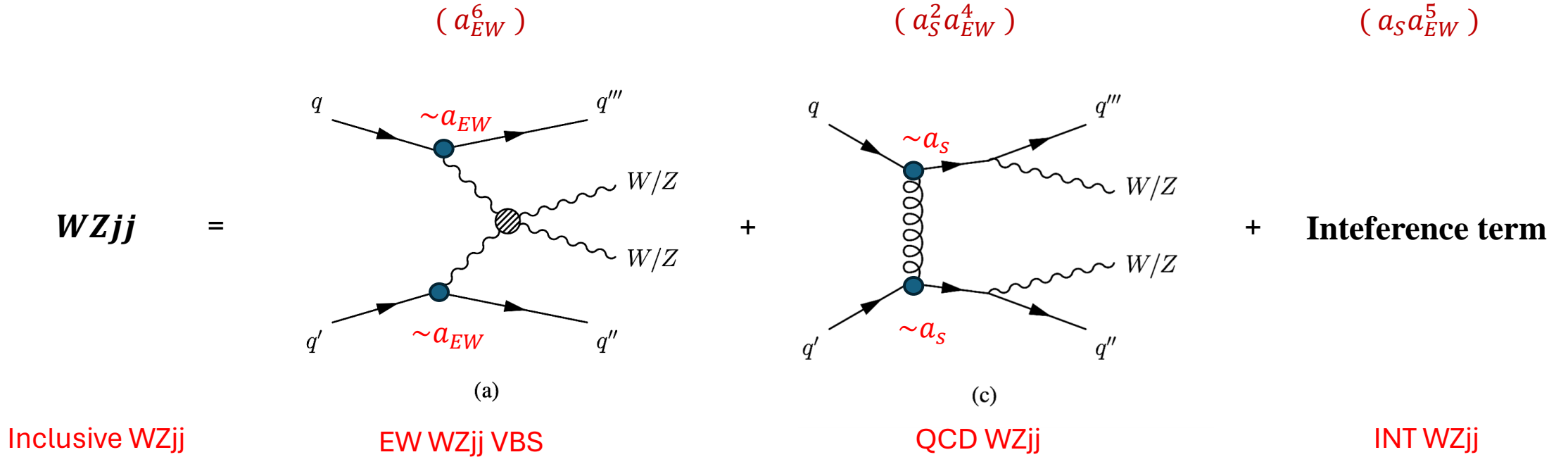


Advantages of PLU

- Fully implemented within TRexFitter
- Systematics are treated normally as part of the Likelihood Function
- Straightforward inclusion of many regions
- Coherence and consistency due to the same formalism applied for all the ATLAS community
- **Simultaneous unfolding constitutes an innovation since it is used for the first time!**

Differential Cross Section Measurements

Measuring the **inclusive** differential cross sections means measuring **the total cross sections** of all the below processes:

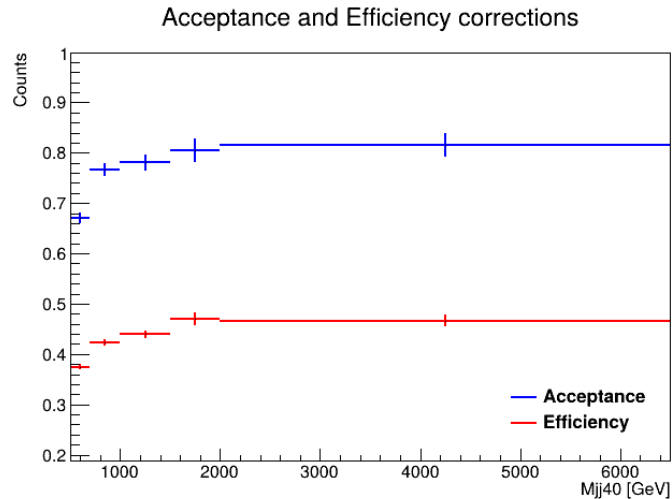


The inclusive process includes **ALL** the above diagrams

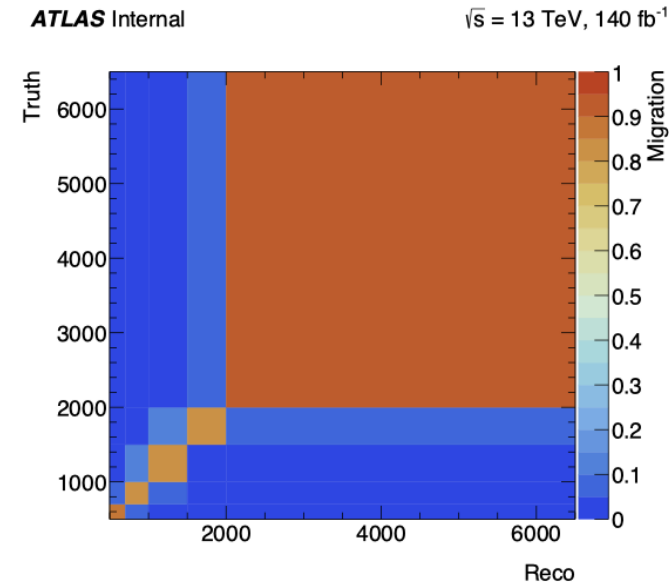
$$R = \frac{1}{\vec{\alpha}} \cdot M \cdot \vec{\epsilon}$$

- Bin 1: $500 < m_{jj} < 700 \text{ GeV}$
- Bin 2: $700 < m_{jj} < 1000 \text{ GeV}$
- Bin 3: $1000 < m_{jj} < 1500 \text{ GeV}$
- Bin 4: $1500 < m_{jj} < 2000 \text{ GeV}$
- Bin 5: $m_{jj} > 2000 \text{ GeV}$

Acceptance ($\vec{\alpha}$) & Efficiency ($\vec{\epsilon}$)

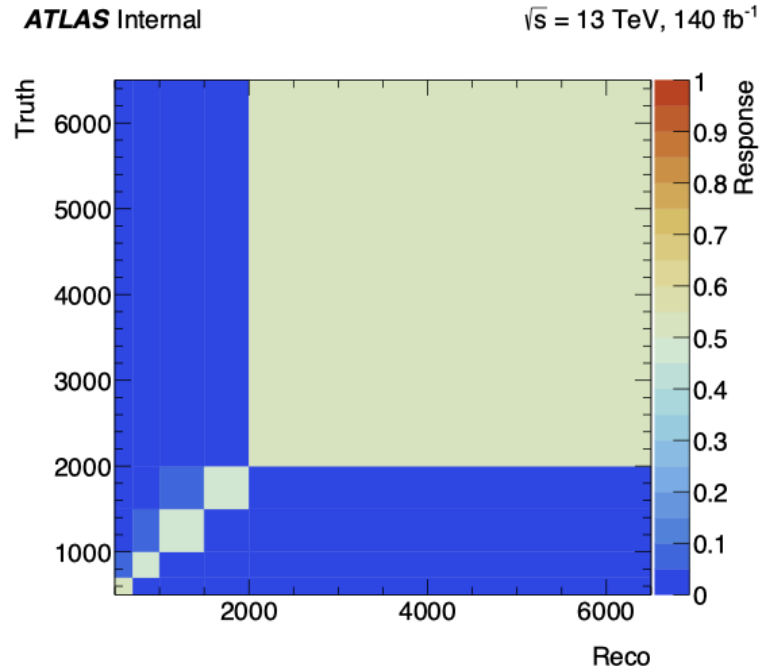


Migration matrix (M)

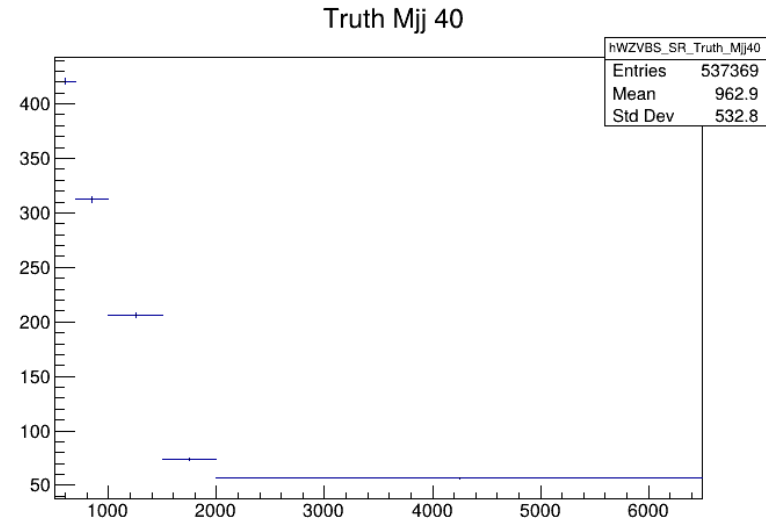


Response Matrix (R)

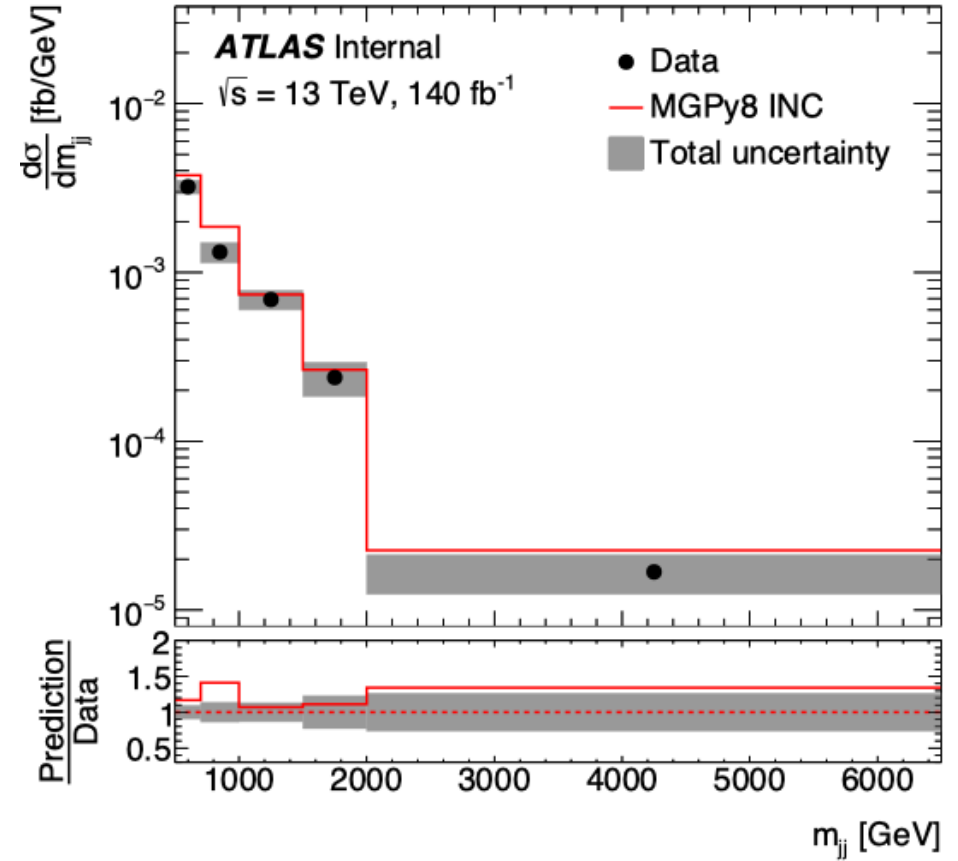
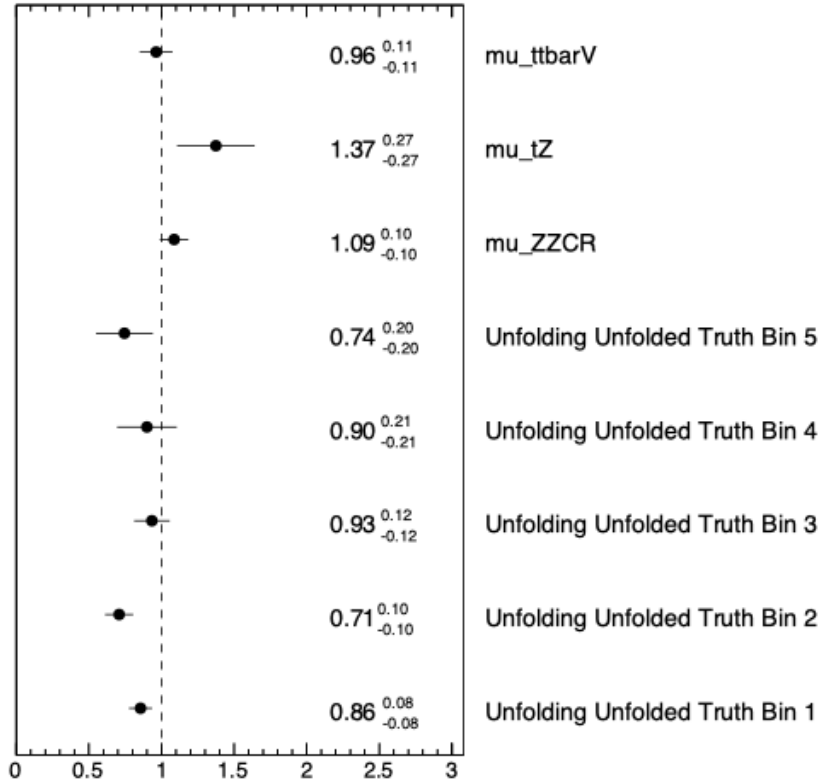
Truth Distribution (**QCD + EW + INT**)



\times



ATLAS Internal



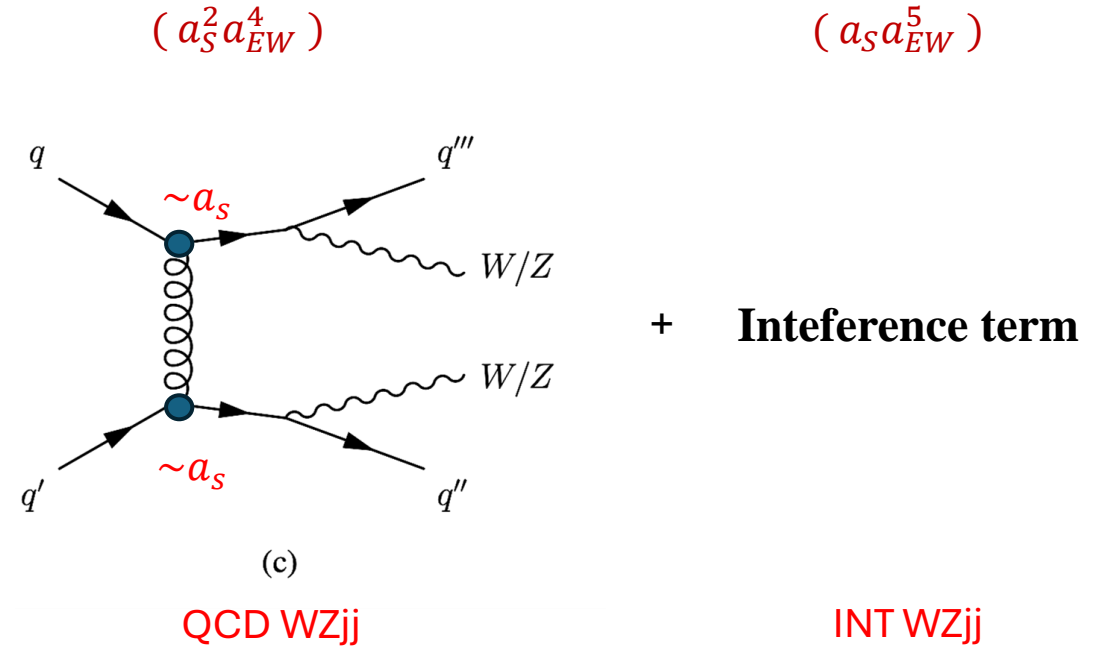
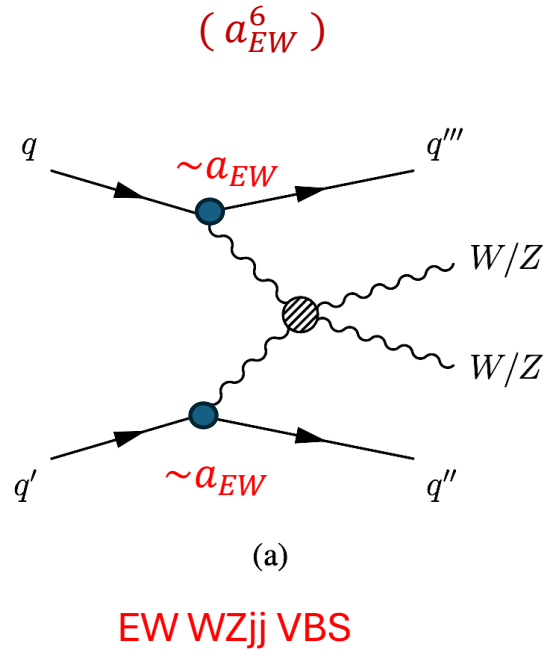
Previous measurement using
Bayesian iterative method

Current measurement using Profile
Likelihood Unfolding Method

Bins (GeV)	$\sigma_{Run2} (fb)$	$\sigma_{PLU} (fb)$
$500 < m_{jj} < 700$	$0.59 \pm 0.06 (stat) \pm 0.03 (syst)$	$0.64 \pm 0.06 (stat)$
$700 < m_{jj} < 1000$	$0.37 \pm 0.05 (stat) \pm 0.03 (syst)$	$0.40 \pm 0.05 (stat)$
$1000 < m_{jj} < 1500$	$0.32 \pm 0.04 (stat) \pm 0.02 (syst)$	$0.35 \pm 0.04 (stat)$
$1500 < m_{jj} < 2000$	$0.11 \pm 0.02 (stat) \pm 0.01 (syst)$	$0.12 \pm 0.03 (stat)$
$m_{jj} > 2000$	$0.07 \pm 0.02 (stat) \pm 0.01 (syst)$	$0.08 \pm 0.02 (stat)$

Systematic uncertainties are not yet included for our results but their implementation is ongoing!

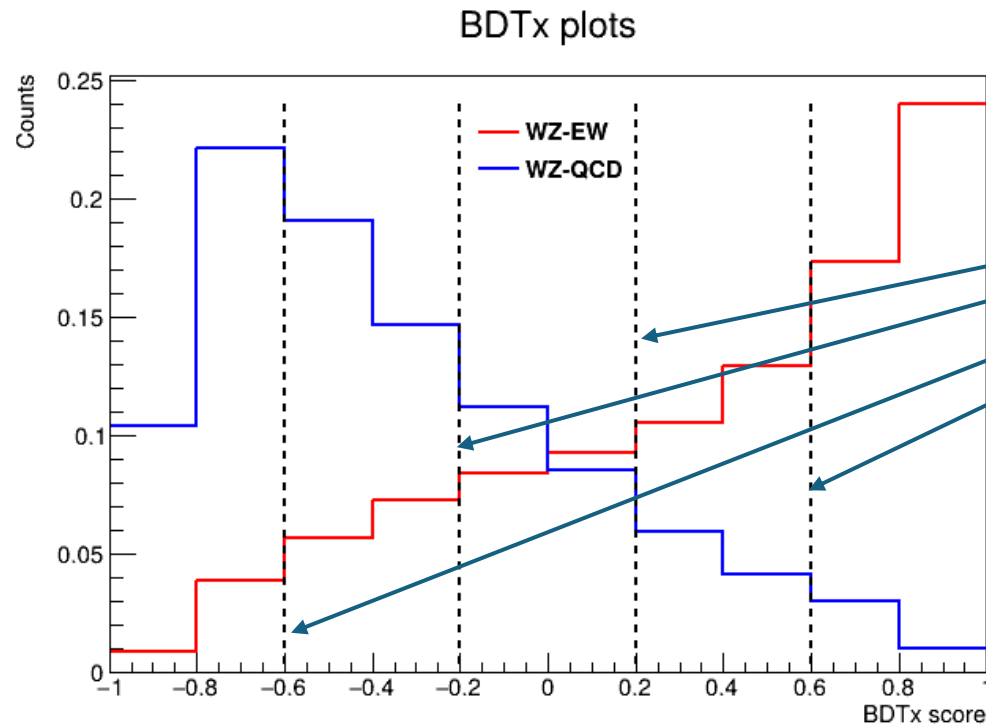
Measuring differential cross sections **simultaneously** means measuring the cross sections the below processes **independently**, but **in the same fit!**



The goal is to measure **simultaneously** the differential cross section of the EW and the QCD+INT processes!

The challenge of this type of fit is the separation of the processes. For this reason we are using machine learning techniques.

Separation based on Boosted Decision Trees



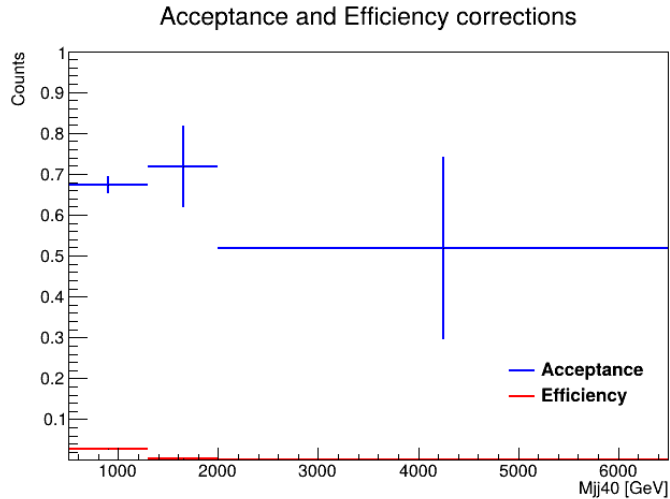
To achieve maximum separation we divide the Singal Region in further regions based on a BDT score cut!

- SR 1: $-1.0 < BDT < -0.6$
- SR 2: $-0.6 < BDT < -0.2$
- SR 3: $-0.2 < BDT < 0.2$
- SR 4: $0.2 < BDT < 0.6$
- SR 5: $0.6 < BDT < 1.0$

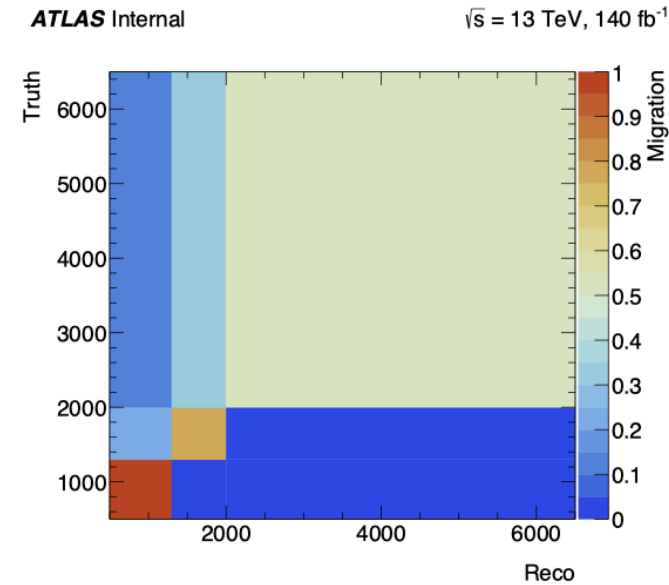
- Bin 1: $500 < m_{jj} < 1300 \text{ GeV}$
- Bin 2: $1300 < m_{jj} < 2000 \text{ GeV}$
- Bin 3: $m_{jj} > 2000 \text{ GeV}$

$$R = \frac{1}{\vec{\alpha}} \cdot M \cdot \vec{\epsilon}$$

Acceptance ($\vec{\alpha}$) & Efficiency ($\vec{\epsilon}$)

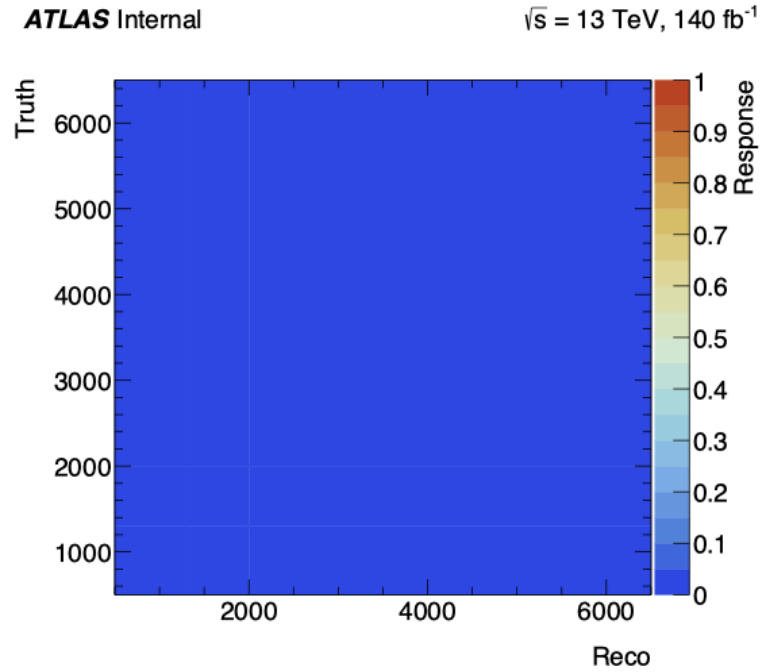


Migration matrix (M)

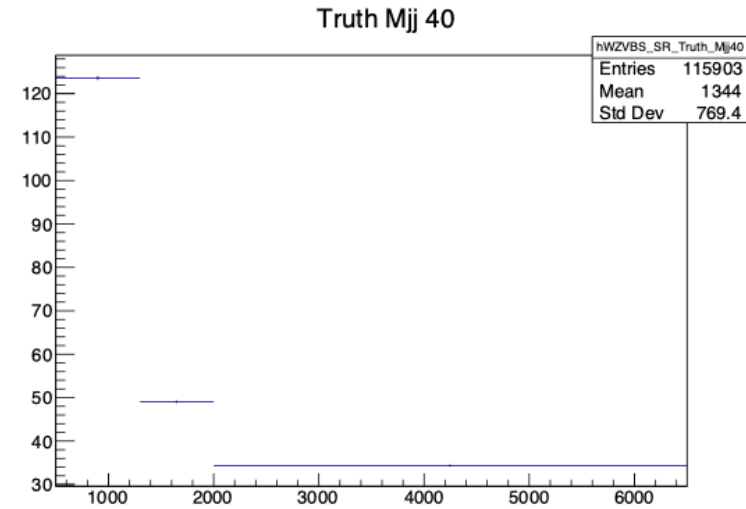


Response Matrix (R)

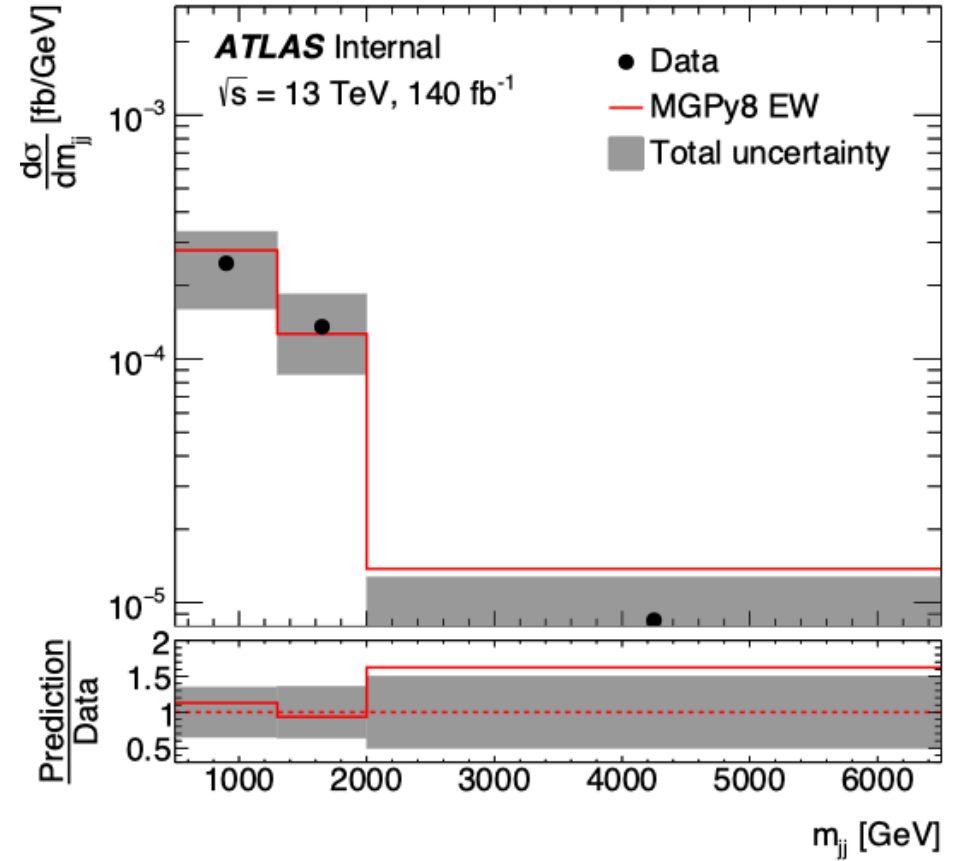
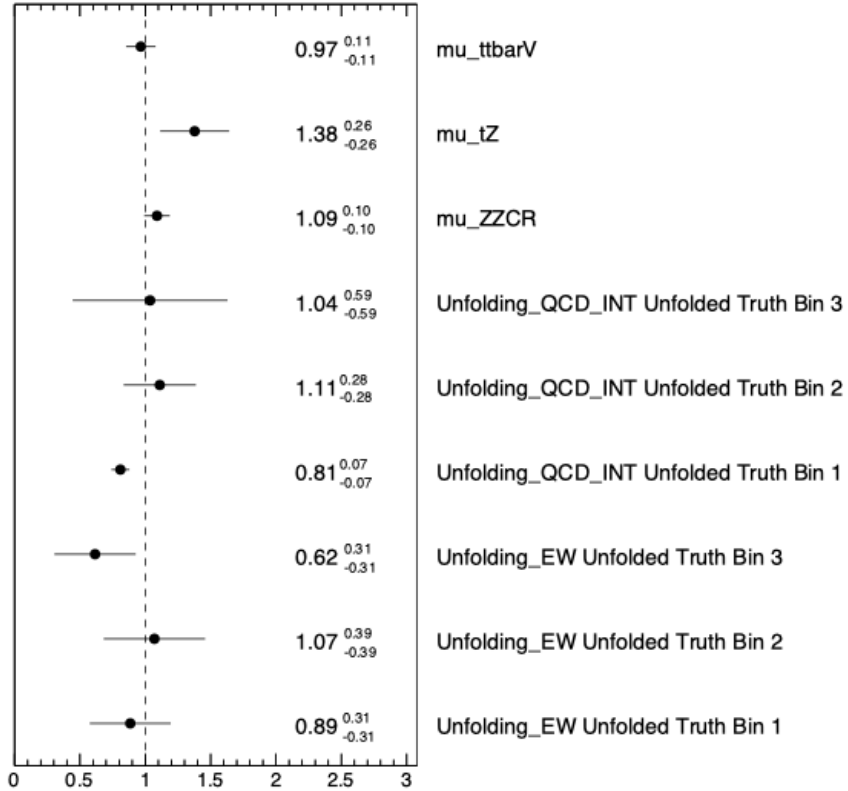
Truth Distribution (EW)



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ATLAS Internal



Previous measurement using
standard bin by bin unfolding

Current measurement using Profile
Likelihood Unfolding Method

Bins (GeV)	$\sigma_{EW,Run2} (fb)$	$\sigma_{EW,PLU} (fb)$
$500 < m_{jj} < 1300$	$0.204 \pm 0.049 (stat) + 0.045 (syst)$	$0.197 \pm 0.068 (stat)$
$1300 < m_{jj} < 2000$	$0.097 \pm 0.023 (stat) + 0.015 (syst)$	$0.095 \pm 0.034 (stat)$
$m_{jj} > 2000$	$0.040 \pm 0.013 (stat) + 0.07 (syst)$	$0.038 \pm 0.019 (stat)$

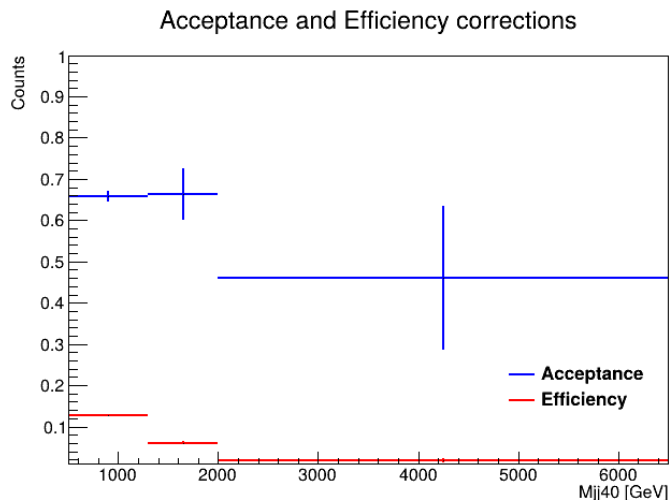
Systematic uncertainties are not yet included for our results but their implementation is ongoing!

- SR 1: $-1.0 < BDT < -0.6$
- SR 2: $-0.6 < BDT < -0.2$
- SR 3: $-0.2 < BDT < 0.2$
- SR 4: $0.2 < BDT < 0.6$
- SR 5: $0.6 < BDT < 1.0$

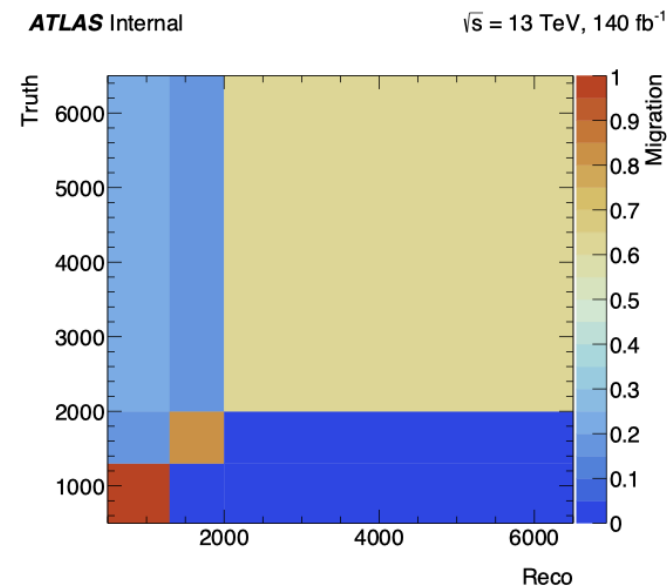
- Bin 1: $500 < m_{jj} < 1300 \text{ GeV}$
- Bin 2: $1300 < m_{jj} < 2000 \text{ GeV}$
- Bin 3: $m_{jj} > 2000 \text{ GeV}$

$$R = \frac{1}{\vec{\alpha}} \cdot M \cdot \vec{\epsilon}$$

Acceptance ($\vec{\alpha}$) & Efficiency ($\vec{\epsilon}$)

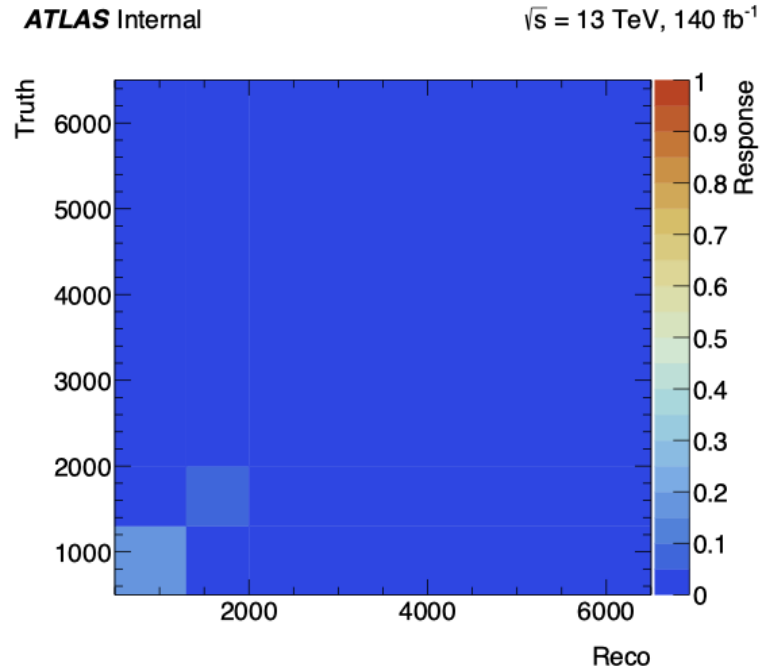


Migration matrix (M)

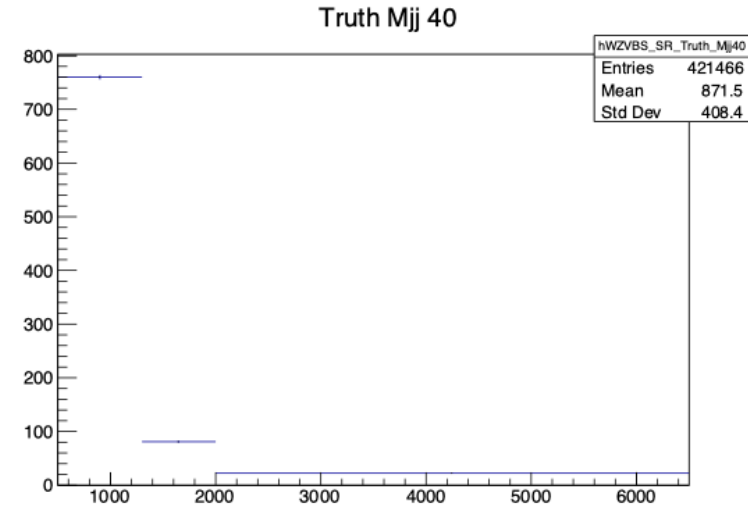


Response Matrix (R)

Truth Distribution (QCD+INT)

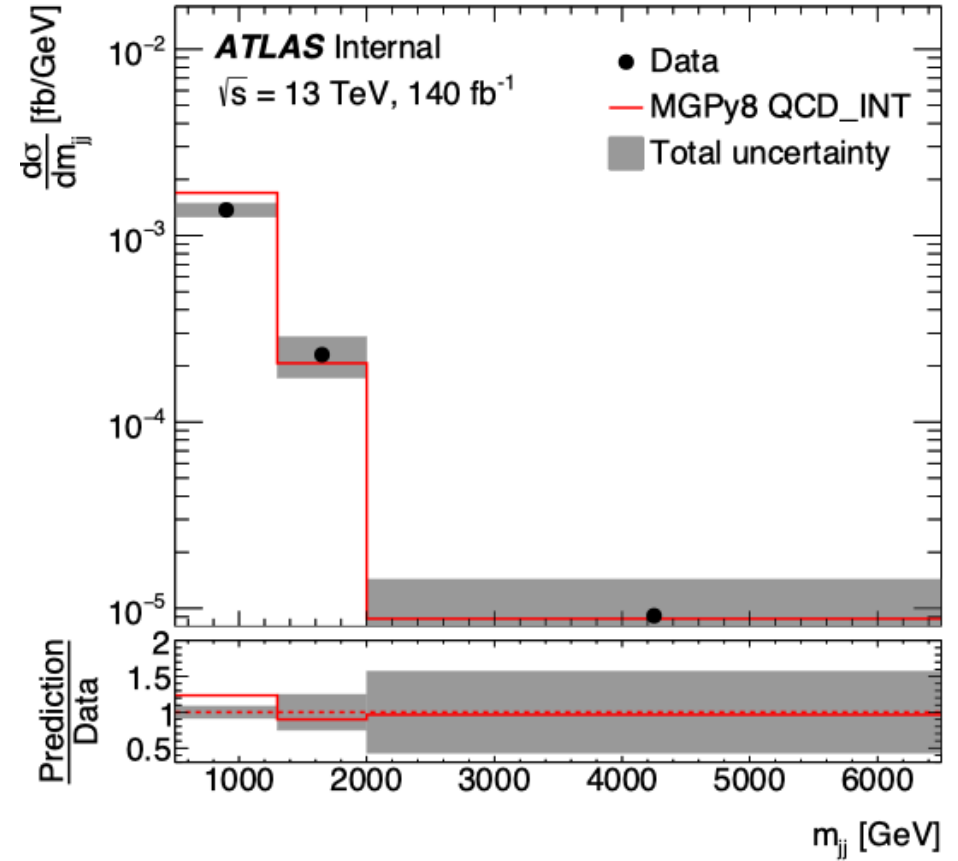
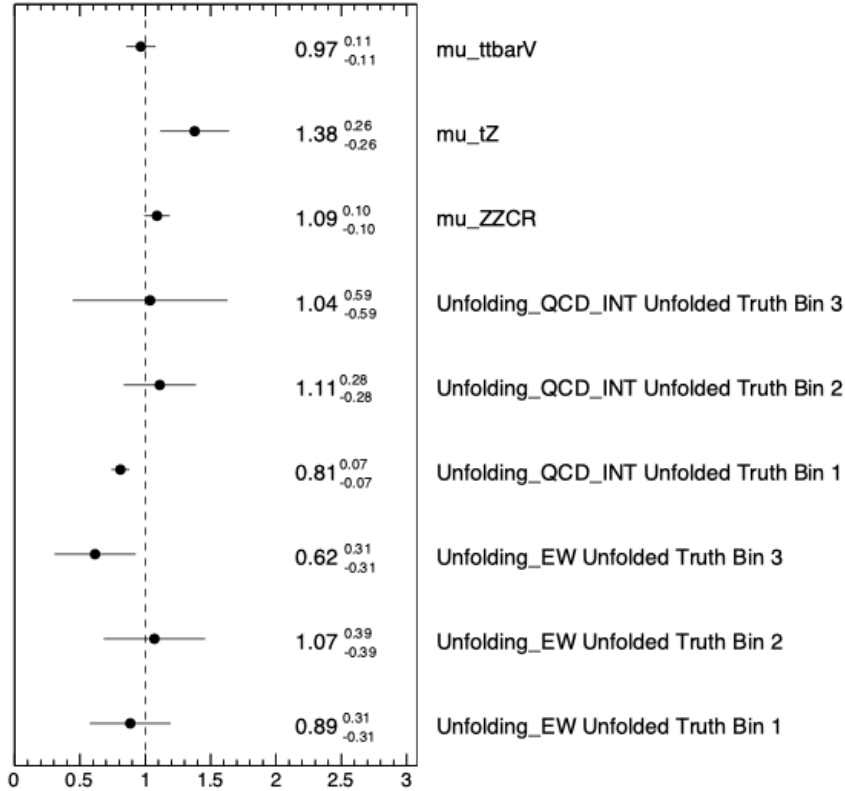


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Data Fit Results – WZ QCD+INT

ATLAS Internal



Previous measurement using
standard bin by bin unfolding

Current measurement using Profile
Likelihood Unfolding Method

Bins (GeV)	$\sigma_{non-EW,Run2} (fb)$	$\sigma_{non-EW,PLU} (fb)$
$500 < m_{jj} < 1300$	$0.956 \pm 0.067 (stat) + 0.096 (syst)$	$1.099 \pm 0.094 (stat)$
$1300 < m_{jj} < 2000$	$0.127 \pm 0.025 (stat) + 0.019 (syst)$	$0.161 \pm 0.040 (stat)$
$m_{jj} > 2000$	$0.030 \pm 0.015 (stat) + 0.009 (syst)$	$0.041 \pm 0.023 (stat)$

Systematic uncertainties are not yet included for our results but their implementation is ongoing!

Conclusions:

- Attempted to reproduce differential cross section measurements of Run2 with the PLU method
- The measurements were performed for both the inclusive and simultaneous fit cases
- The PLU method is producing reliable results with respect to already performed measurements for both cases
- Results were validated across different variables
- The machinery for Run3 is almost ready, first Asimov fit studies have already been performed

Next steps:

- Systematic uncertainties need to be inserted in the fit
- With the addition of the 2025 dataset, the luminosity is expected to increase by a factor of ~ 2 , so binning optimisation studies need to be performed (Preliminary studies have already been presented)
- Perform studies to check potential Run2 and Run3 combined measurements

Successfully registered training hours:

- Physics in the XXIst Century (13 March – 22 May 2025, 20 hours)
- Français Langue Etrangère (20 January – 18 April 2025, 45 hours)
- Constuire son Projet Professionnel (26 March – 27 March 2025, 12h)
- Journée de rentrée des doctorants (14 November 2024, 4h)
- Job Hunting Strategies (20 October – 22 October 2025, 21 h)
- MOOC PhD and Carreer Development (13 January – 24 February 2026, 12h)
- MOOC Ethique de la recherche – Univ. Lyon (20 October 2025 – 21 June 2026, 15h, **Mandatory**) ✓
- MOOC Research integrity in scientific professions - Univ. Bordeaux (01 September 2025 – 31 August 2026, 15h, **Mandatory**) ✓
- Gender based and sexual violence, discrimination and harassment (**Mandatory**) ✗ (Not validated yet)

 210 heures réalisées / 120 heures requises

Summer Schools:

- Gray Scott Computing School (L.A.P.P., Annecy, 23 June – 4 July 2025)
- IN2P3 School of Statistics (Centre Paul-Langevin, Aussois, 31 May – 5 June 2026)

Talks and conferences:

- Physique ATLAS France (Conference, Annecy, 26 May – 28 May 2025)
- Congrès Général de la Société Française de Physique (Talk: Studying the VBS process, Troyes, 30 June – 4 July 2025)
- Journées de Rencontre des Jeunes Chercheur.ses.s (Talk: Measurement of the electroweak diboson production in the $W^\pm Z$ channel with the ATLAS detector at LHC, Saint-Jacut de la mer, 30 November – 6 December 2025)
- WZ leptonic weekly meeting (Bi-weekly progress presentation)
- PMG Weak Boson meeting (QP progress presentation and finalization)
- Shifts in the ATLAS Control Room

THANKS FOR YOUR ATTENTION!

Backup Slides

Phase Spaces

	Variable	Fiducial $WZjj$ -EW
Fiducial Inclusive	Lepton $ \eta $	< 2.5
	p_T of ℓ_Z, p_T of ℓ_W [GeV]	$> 15, > 20$
	m_Z range [GeV]	$ m_Z - m_Z^{\text{PDG}} < 10$
	m_T^W [GeV]	> 30
	$\Delta R(\ell_Z^-, \ell_Z^+), \Delta R(\ell_Z, \ell_W)$	$> 0.2, > 0.3$
	p_T two leading jets [GeV]	> 40
	$ \eta_j $ two leading jets	< 4.5
	Jet multiplicity	≥ 2
	$\eta_{j1} \cdot \eta_{j1}$	< 0
	m_{jj} [GeV]	> 500
	$\Delta R(j, \ell)$	> 0.3
	$N_{b\text{-quark}}$	$= 0$

Fiducial $WZjj$ – EW
Signal Region

Unfolding is treated by Profile Likelihood Unfolding as a scaling factor estimation problem!

$$L(\mu, \vec{k}, \vec{\theta}, \vec{\gamma}) = \prod_{i \in \text{bins}} \text{Pois}(n_i | (\mu s_i(\vec{\theta}) + k b_i(\vec{\theta})) \gamma_i) \times \prod_{j \in \text{syst}} C(\theta_j | 0, 1) \times \prod_{i \in \text{bins}} C(\gamma_i | 1, \sigma_{\gamma_i})$$

- μ → Parameter Of Interest (POI) → Unconstrained
- k → Background Normalization parameters → Unconstrained
- $\vec{\theta}$ → Nuisance parameters to account for systematic uncertainties → Follow Gaussian distributions with $\mu = 0$, $\sigma = 1$
- γ_i → Nuisance parameters to account for finite MC statistics → Follow Gaussian distributions with $\mu = 1$, σ_{γ_i}

Inclusive fit:

- N_{jets} with $p_T > 40 GeV$ (Run2, Data fit) ✓
- m_{WZ}^T (Run2, Data fit) ✓
- N_{jets} with $p_T > 40 GeV$ (Run3, Asimov fit) ✓
- m_{WZ}^T (Run3, Asimov fit) ✓

Simultaneous fit:

- N_{jets} with $p_T > 25 GeV$ (Run2, Data fit) ✓
- m_{jj} (Run3, Asimov fit) ✓
- N_{jets} with $p_T > 25 GeV$ (Run3, Asimov fit) ✓

Studied variables but
not shown today due to
lack of time!

Run2 studies

Inclusive Fit

To perform the fit we divide the phase space in the following regions:

- **WZ VBS Signal Region** {
 - Region where we expect to have the most signal
 - Measurements are performed in this region

- **ZZ Control Region** {
 - Region rich in the ZZ background events
 - Used to constrain the ZZ background

- **b CR** {
 - Region with at least one b-quark jet
 - Used to constrain the background $\bar{t}tV$ and tZ background processes

We introduce scaling factors simultaneously estimated in the SR+CRs:

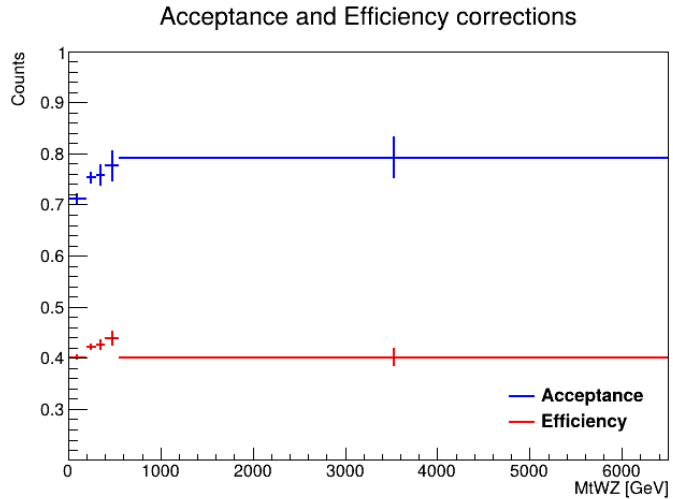
- $\mu_{truth_bin1}, \dots, \mu_{truth_binN}$
- $\mu_{ZZ_{QCD}}$ (SR, ZZCR)
- $\mu_{\bar{t}tV}$ (SR, ZZCR, b CR)
- μ_{tZ} (SR, ZZCR, b CR)

**Run2 Data Fit
(2015 - 2018)**

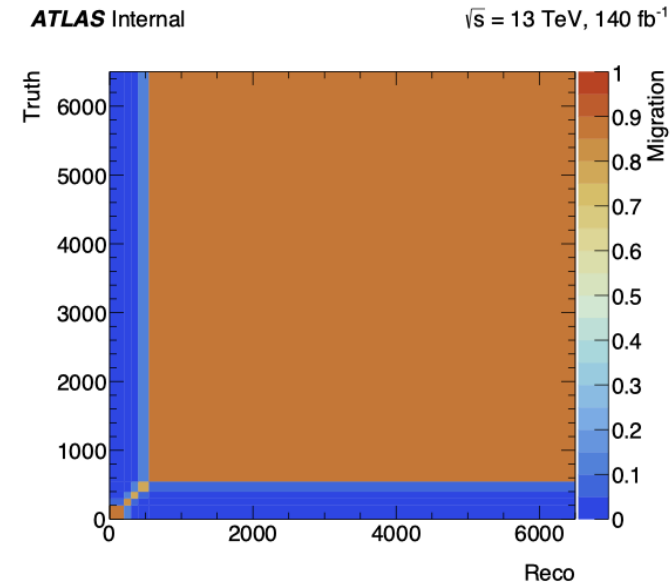
$$R = \frac{1}{\vec{\alpha}} \cdot M \cdot \vec{\epsilon}$$

- Bin 1: $0 < m_T^{WZ} < 200 \text{ GeV}$
- Bin 2: $200 < m_T^{WZ} < 300 \text{ GeV}$
- Bin 3: $300 < m_T^{WZ} < 400 \text{ GeV}$
- Bin 4: $400 < m_T^{WZ} < 550 \text{ GeV}$
- Bin 5: $m_T^{WZ} > 550 \text{ GeV}$

Acceptance ($\vec{\alpha}$) & Efficiency ($\vec{\epsilon}$)

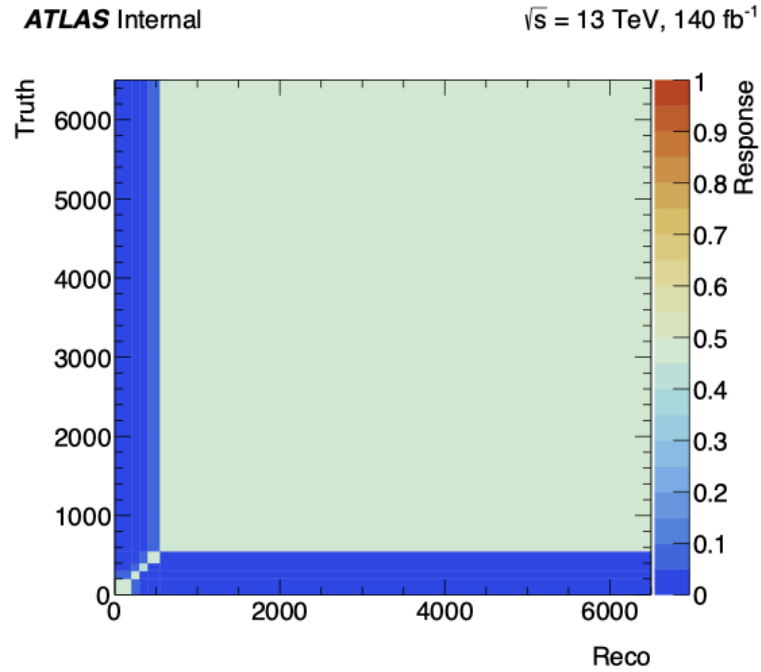


Migration matrix (M)

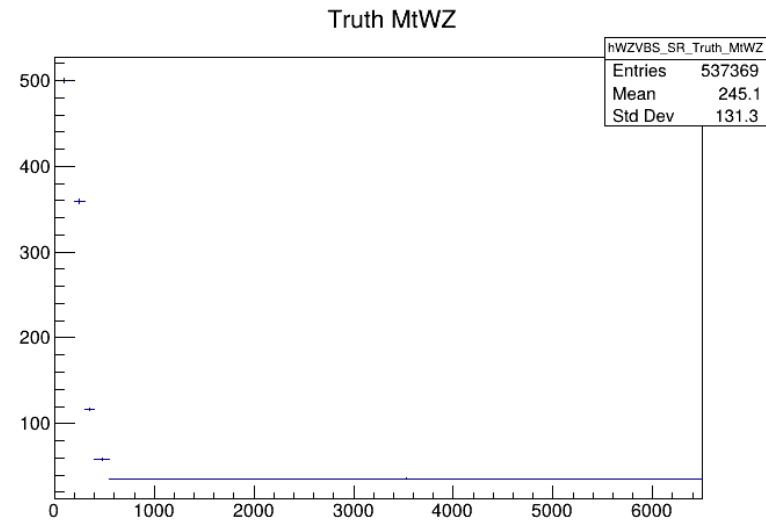


Response Matrix (R)

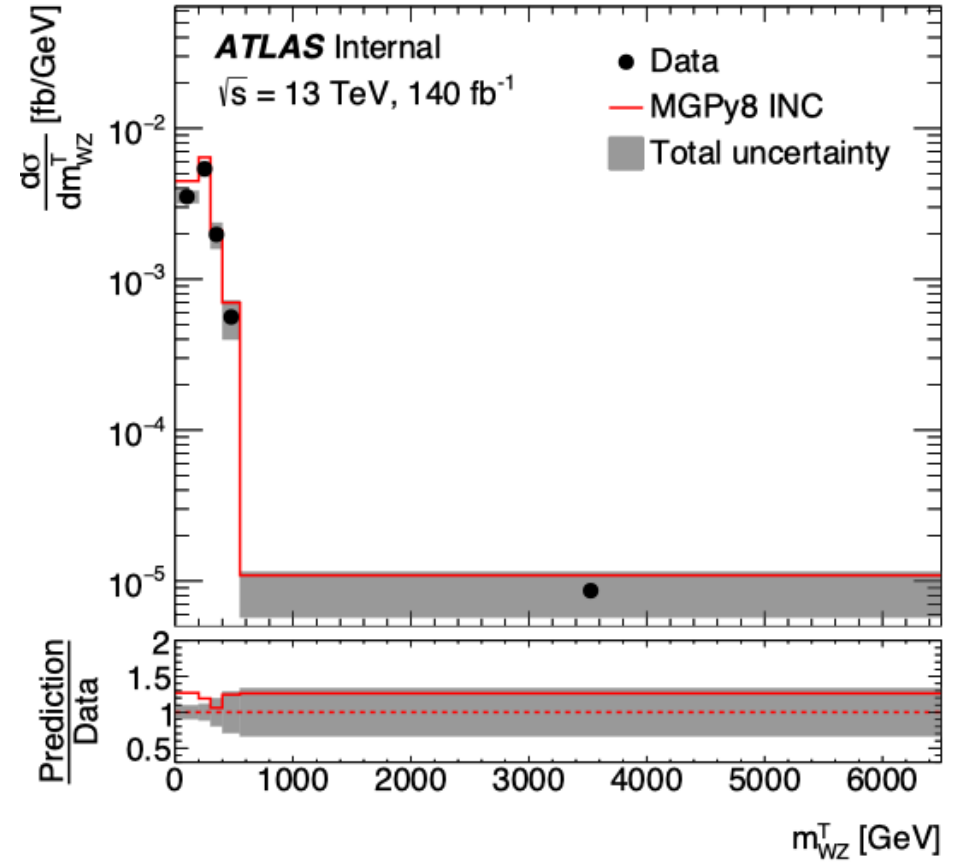
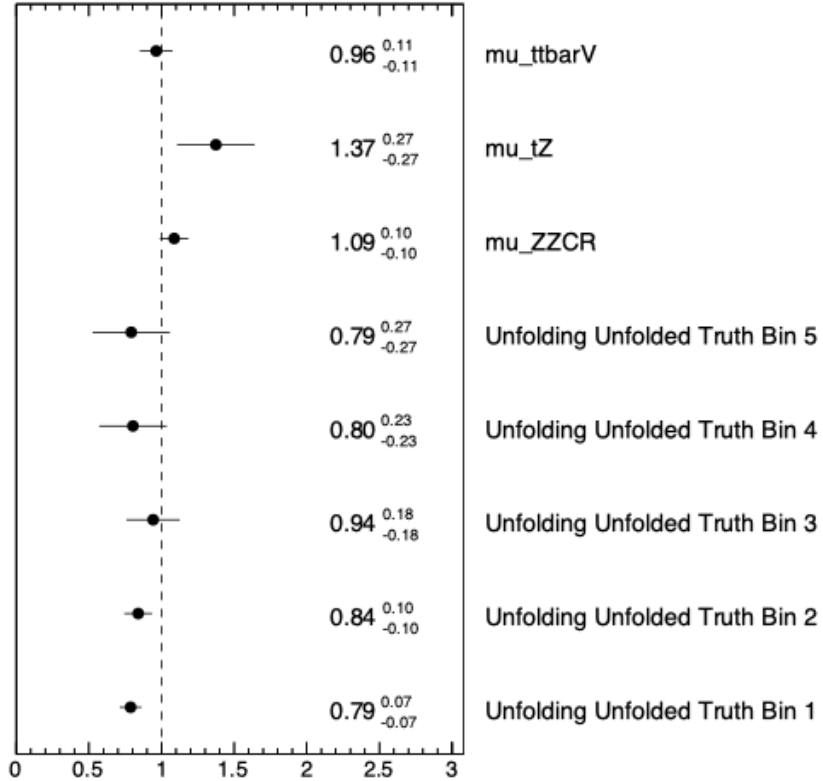
Truth Distribution (**QCD + EW + INT**)



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ATLAS Internal



Previous measurement using
Bayesian iterative method

Current measurement using Profile
Likelihood Unfolding Method

Bins (GeV)	σ_{Run2} (fb)	σ_{PLU} (fb)
$0 < m_T^{WZ} < 200$	0.64 ± 0.06 (stat) ± 0.05 (syst)	0.70 ± 0.07 (stat)
$200 < m_T^{WZ} < 300$	0.51 ± 0.06 (stat) ± 0.03 (syst)	0.54 ± 0.06 (stat)
$300 < m_T^{WZ} < 400$	0.18 ± 0.03 (stat) ± 0.01 (syst)	0.20 ± 0.04 (stat)
$400 < m_T^{WZ} < 550$	0.08 ± 0.02 (stat) ± 0.01 (syst)	0.08 ± 0.02 (stat)
$m_T^{WZ} > 550$	0.05 ± 0.02 (stat) ± 0.00 (syst)	0.05 ± 0.02 (stat)

Systematic uncertainties are not yet included for our results but their implementation is ongoing!

Simultaneous Fit

To perform the fit we divide the phase space in the following regions:

- One WZ VBS Signal Region per BDT bin
 - Region where we expect to have the most signal
 - Achieves maximum separation between processes
- ZZ Control Region
 - Region rich in the ZZ background events
 - Used to constrain the ZZ background
- b CR
 - Region with at least one b-quark jet
 - Used to constrain the background $\bar{t}tV$ and tZ background processes

We introduce scaling factors simultaneously estimated in the SR+CRs:

- $\mu_{truth_bin1}, \dots, \mu_{truth_binN}$ for each unfolded process (EW and QCD+INT)
- $\mu_{ZZ_{QCD}}$ (SRs, ZZCR)
- $\mu_{\bar{t}tV}$ (SRs, ZZCR, b CR)
- μ_{tZ} (SRs, ZZCR, b CR)

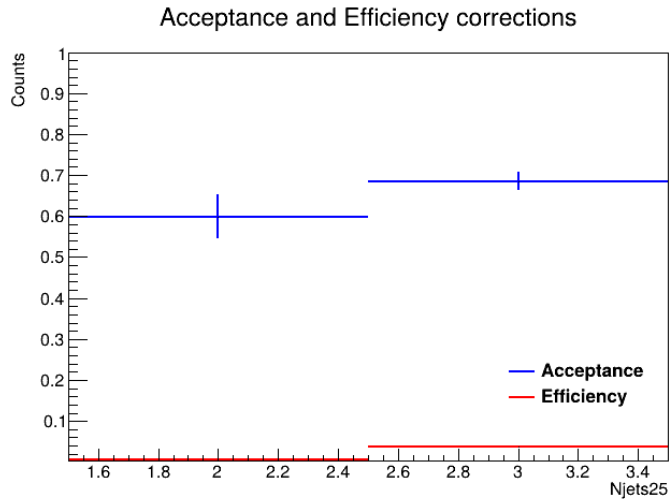
**Run2 Data Fit
(2015 - 2018)**

- SR 1: $-1.0 < BDT < -0.6$
- SR 2: $-0.6 < BDT < -0.2$
- SR 3: $-0.2 < BDT < 0.2$
- SR 4: $0.2 < BDT < 0.6$
- SR 5: $0.6 < BDT < 1.0$

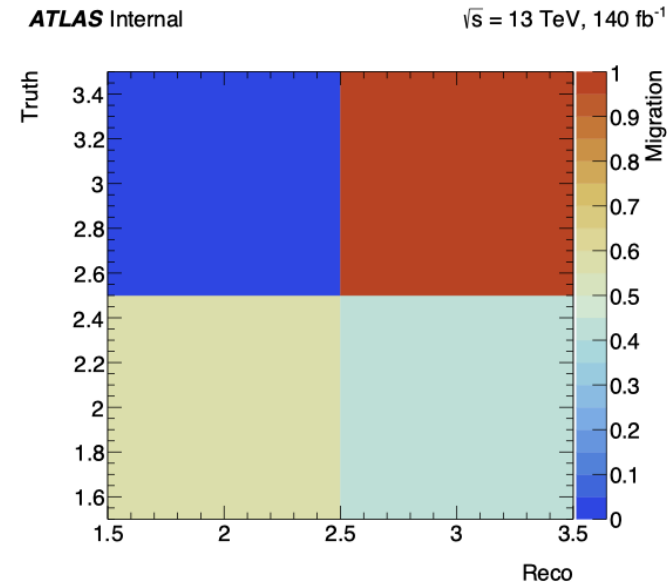
- Bin 1: $N_{jets} = 2$
- Bin 2: $N_{jets} > 2$

$$R = \frac{1}{\vec{\alpha}} \cdot M \cdot \vec{\epsilon}$$

Acceptance ($\vec{\alpha}$) & Efficiency ($\vec{\epsilon}$)

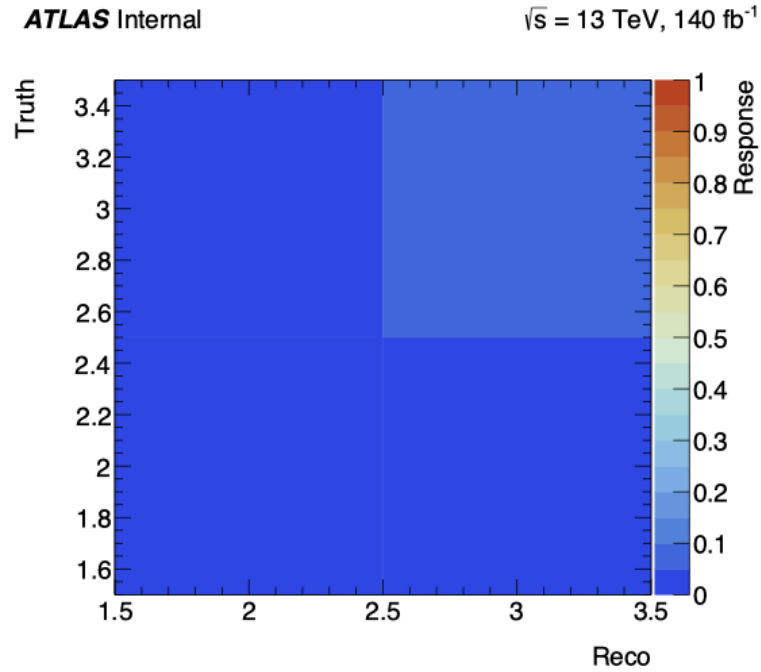


Migration matrix (M)

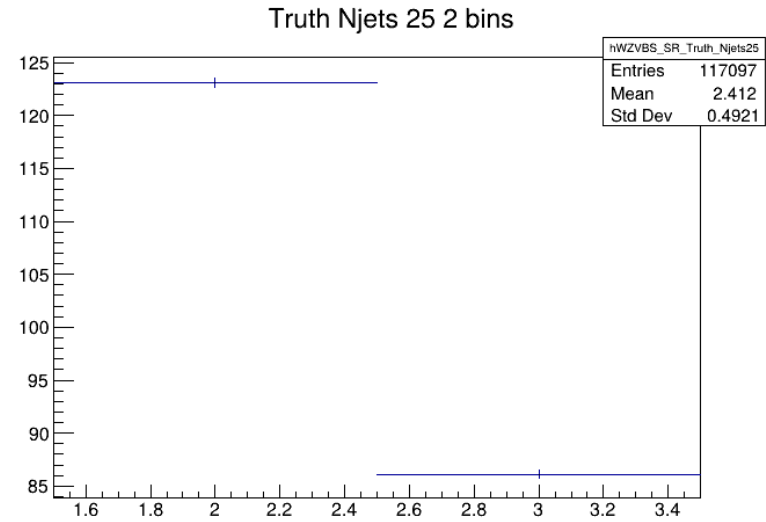


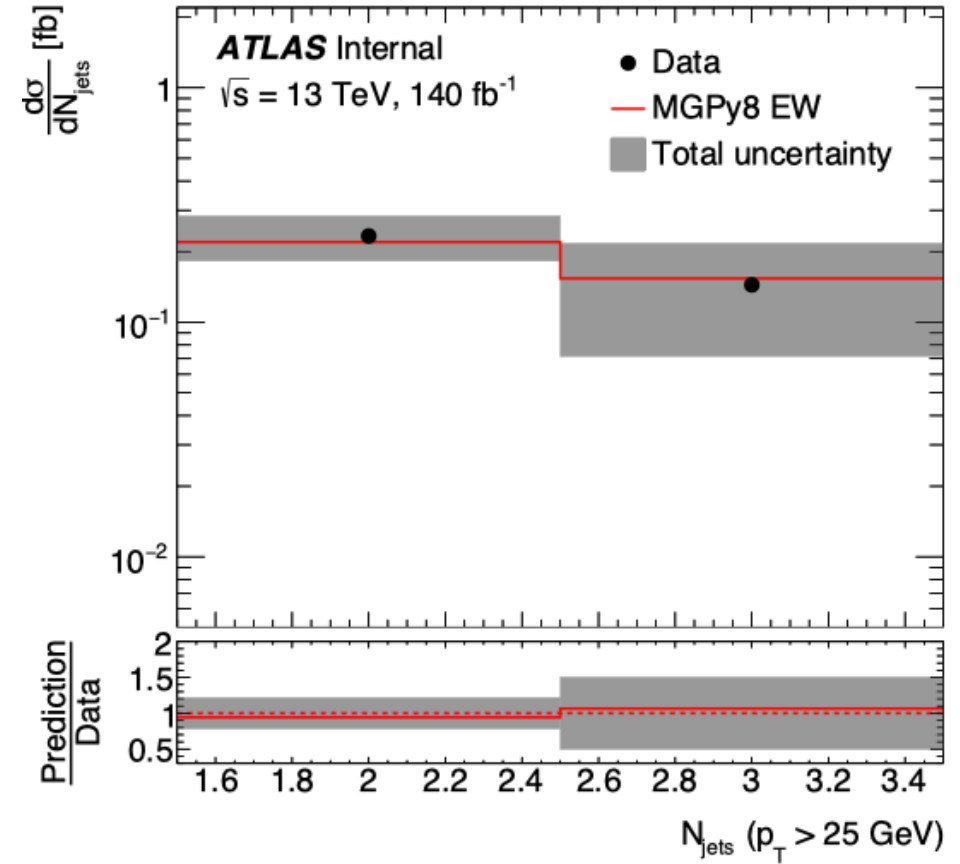
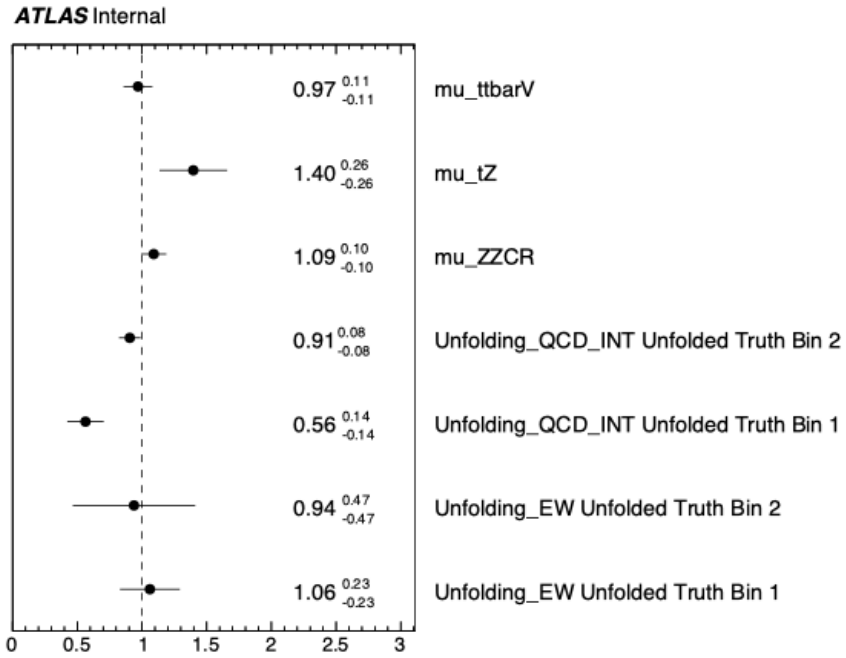
Response Matrix (R)

Truth Distribution (EW)



\times





Previous measurement using
standard bin by bin method

Current measurement using Profile
Likelihood Unfolding Method

Bins (GeV)	$\sigma_{EW,Run2} (fb)$	$\sigma_{EW,PLU} (fb)$
$N_{jets} = 2$	$0.232 \pm 0.037 (stat) + 0.035 (syst)$	$0.233 \pm 0.051 (stat)$
$N_{jets} > 2$	$0.136 \pm 0.037 (stat) + 0.031 (syst)$	$0.144 \pm 0.073 (stat)$

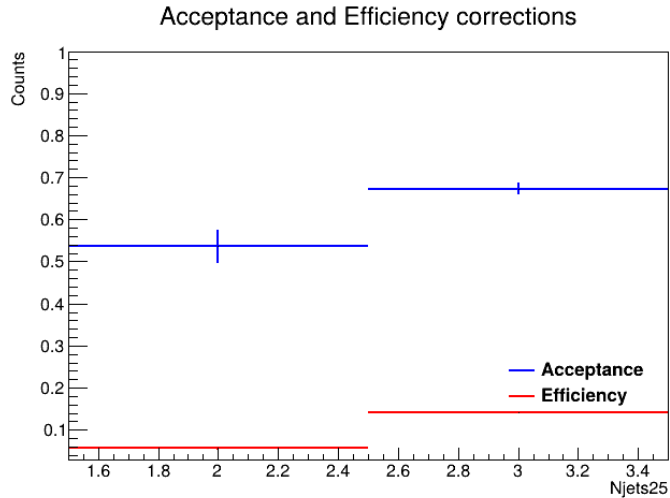
Systematic uncertainties are not yet included for our results but their implementation is ongoing!

- SR 1: $-1.0 < BDT < -0.6$
- SR 2: $-0.6 < BDT < -0.2$
- SR 3: $-0.2 < BDT < 0.2$
- SR 4: $0.2 < BDT < 0.6$
- SR 5: $0.6 < BDT < 1.0$

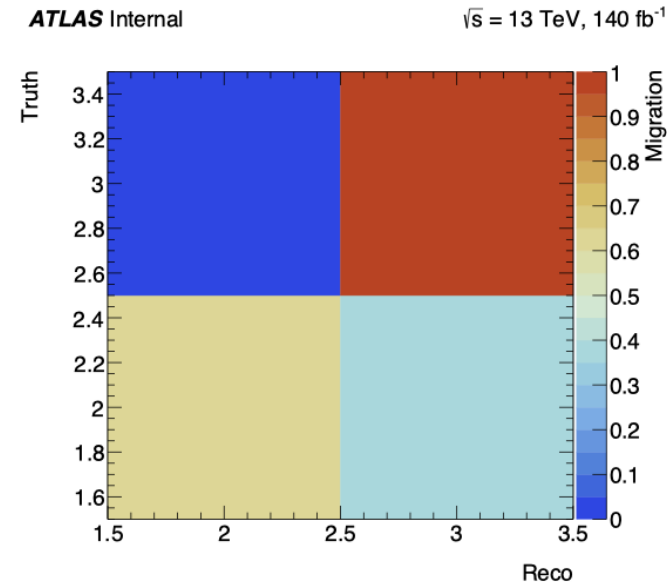
- Bin 1: $N_{jets} = 2$
- Bin 2: $N_{jets} > 2$

$$R = \frac{1}{\vec{\alpha}} \cdot M \cdot \vec{\epsilon}$$

Acceptance ($\vec{\alpha}$) & Efficiency ($\vec{\epsilon}$)

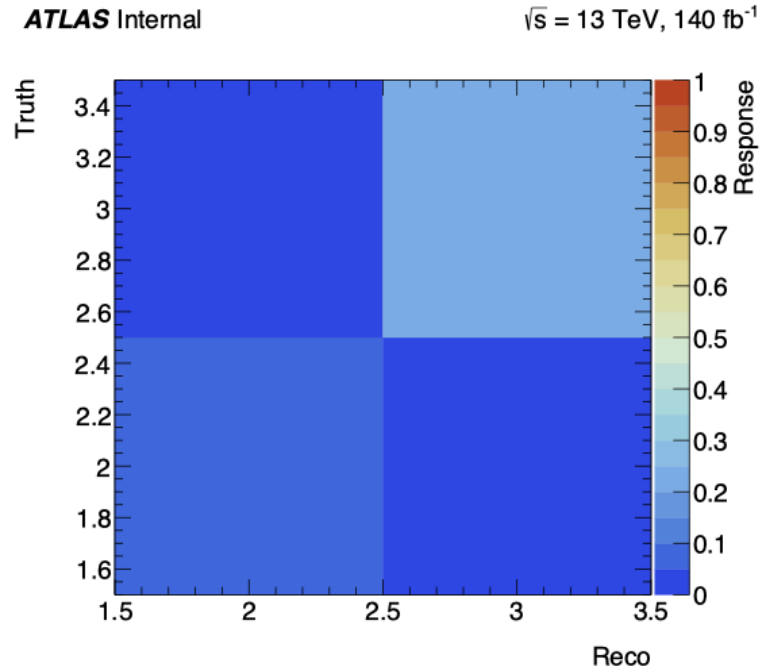


Migration matrix (M)

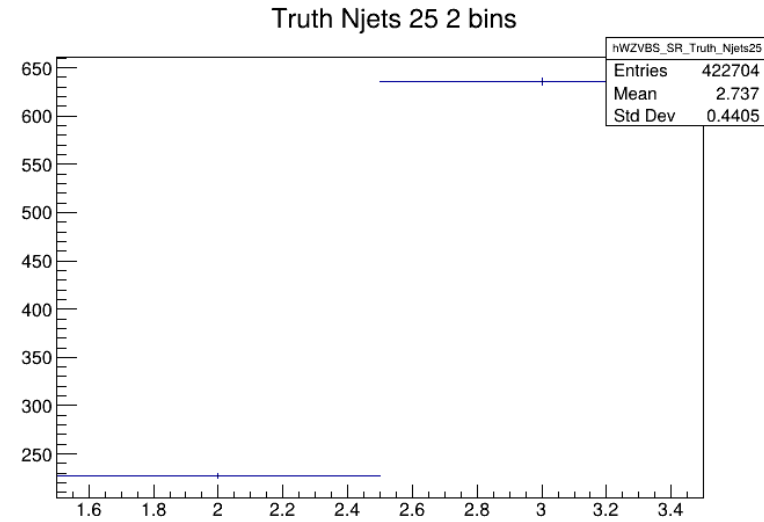


Response Matrix (R)

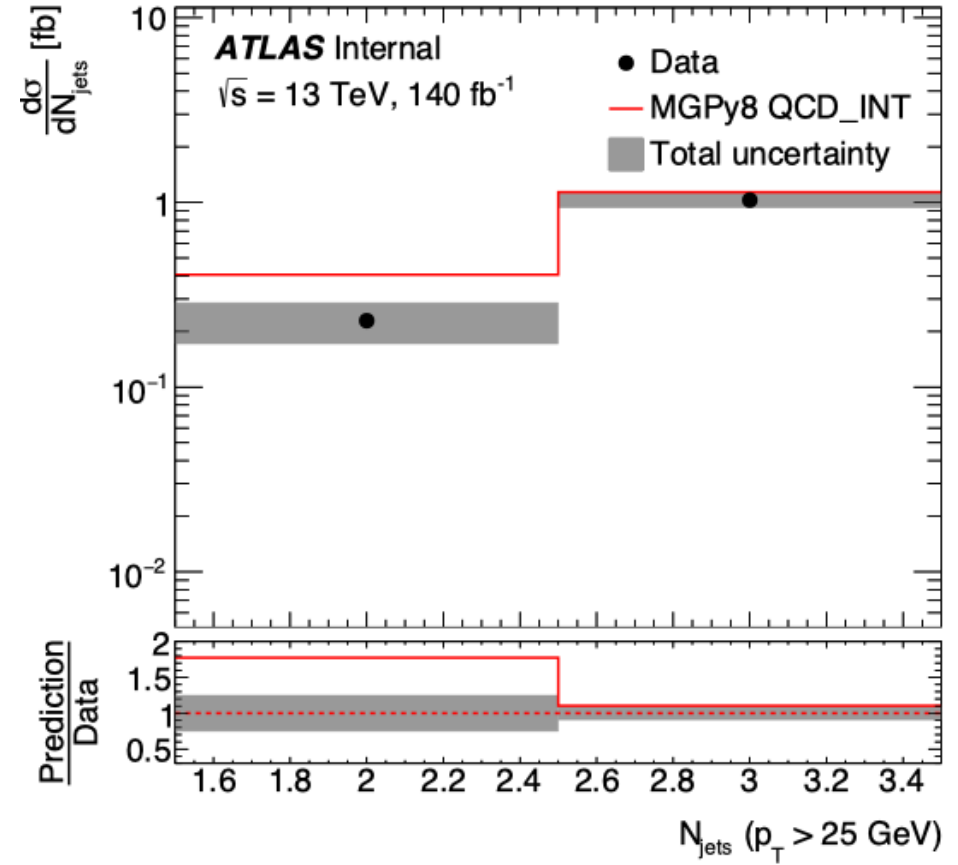
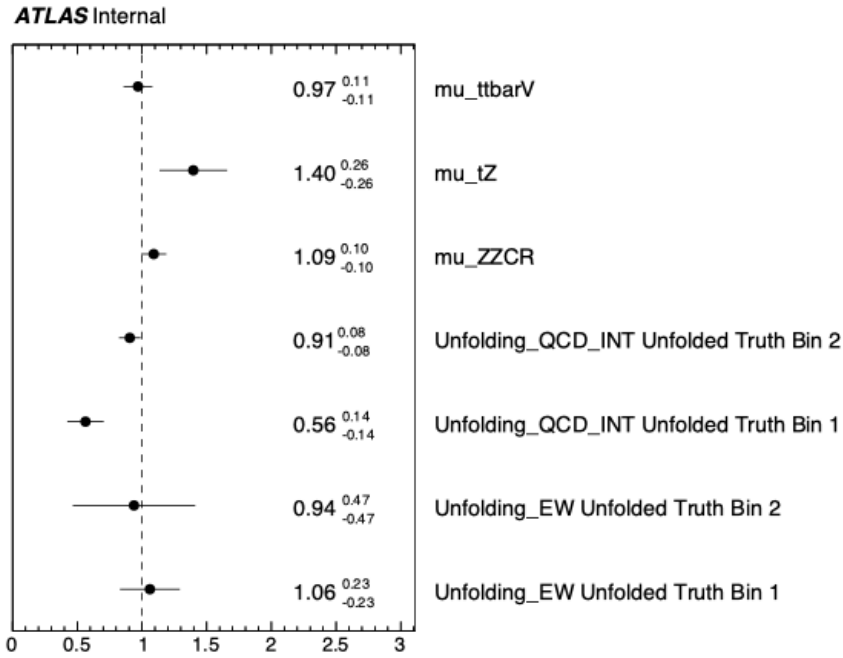
Truth Distribution (QCD+INT)



×



Data Fit Results – WZ QCD+INT



Previous measurement using
standard bin by bin method

Current measurement using Profile
Likelihood Unfolding Method

Bins (GeV)	$\sigma_{non-EW,Run2}$ (fb)	$\sigma_{non-EW,PLU}$ (fb)
$N_{jets} = 2$	0.189 ± 0.038 (stat) + 0.036 (syst)	0.229 ± 0.057 (stat)
$N_{jets} > 2$	0.905 ± 0.063 (stat) + 0.012 (syst)	1.028 ± 0.095 (stat)

Systematic uncertainties are not yet included for our results but their implementation is ongoing!

Run3 studies

Inclusive Fit

m_{jj}

- Bin 1: $500 < m_{jj} < 700 \text{ GeV}$
- Bin 2: $700 < m_{jj} < 1000 \text{ GeV}$
- Bin 3: $1000 < m_{jj} < 1500 \text{ GeV}$
- Bin 4: $1500 < m_{jj} < 2000 \text{ GeV}$
- Bin 5: $m_{jj} > 2000 \text{ GeV}$

N_{jets}

- Bin 1: $N_{jets} = 2$
- Bin 2: $N_{jets} = 3$
- Bin 3: $N_{jets} = 4$
- Bin 4: $N_{jets} \geq 5$

WZjj Inclusive

To perform the fit we divide the phase space in the following regions:

- **WZ VBS Signal Region** {
 - Region where we expect to have the most signal
 - Measurements are performed in this region

- **ZZ Control Region** {
 - Region rich in the ZZ background events
 - Used to constrain the ZZ background

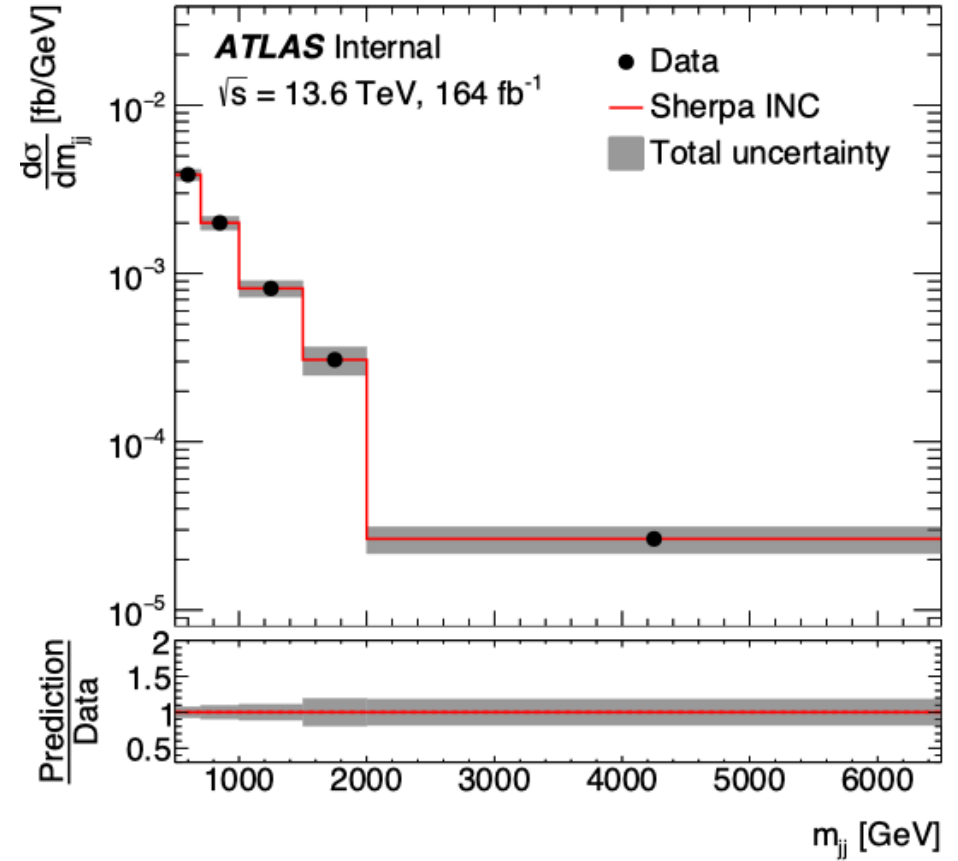
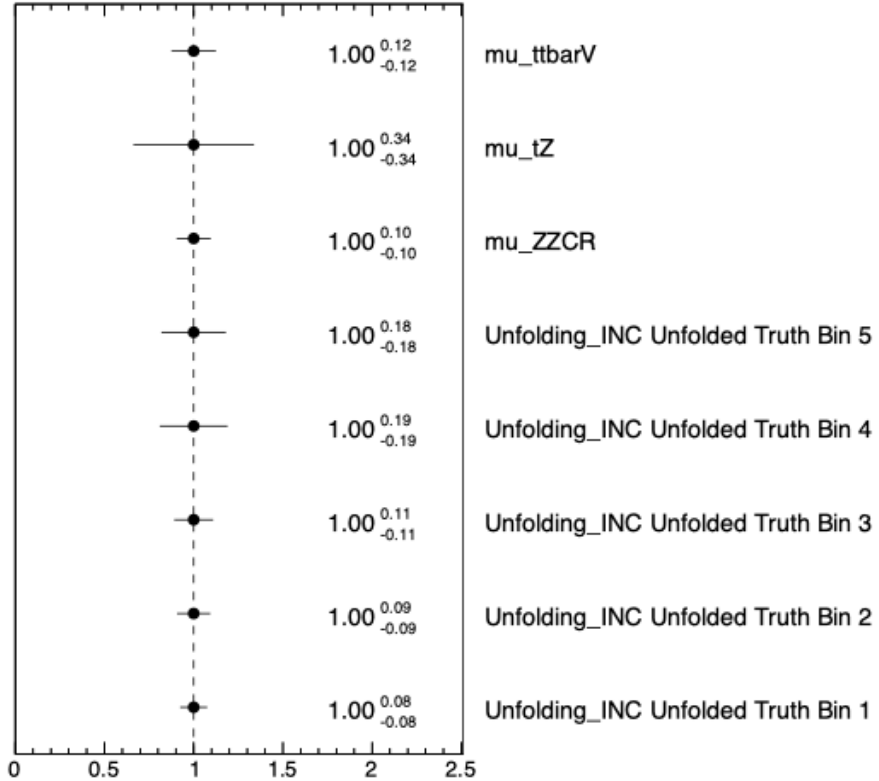
- **b CR** {
 - Region with at least one b-quark jet
 - Used to constrain the background $\bar{t}tV$ and tZ background processes

We introduce scaling factors simultaneously estimated in the SR+CRs:

- $\mu_{truth_bin1}, \dots, \mu_{truth_binN}$
- $\mu_{ZZ_{QCD}}$ (SR, ZZCR)
- $\mu_{\bar{t}tV}$ (SR, ZZCR, b CR)
- μ_{tZ} (SR, ZZCR, b CR)

Asimov Dataset Fit

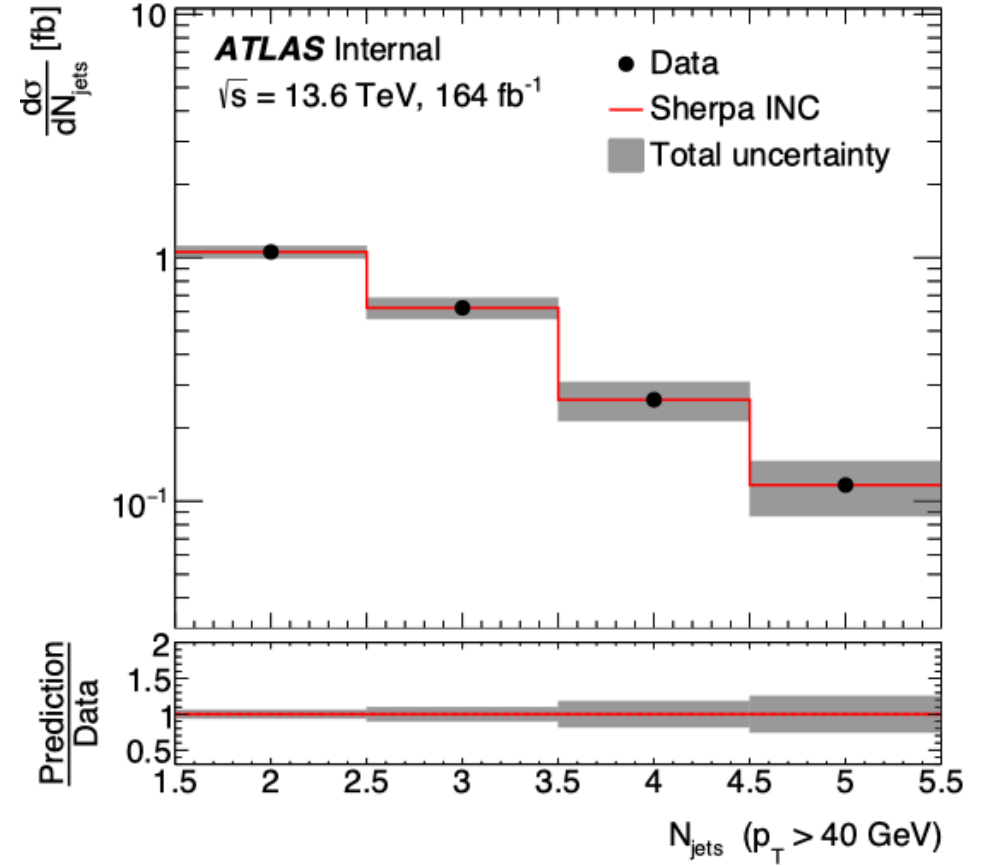
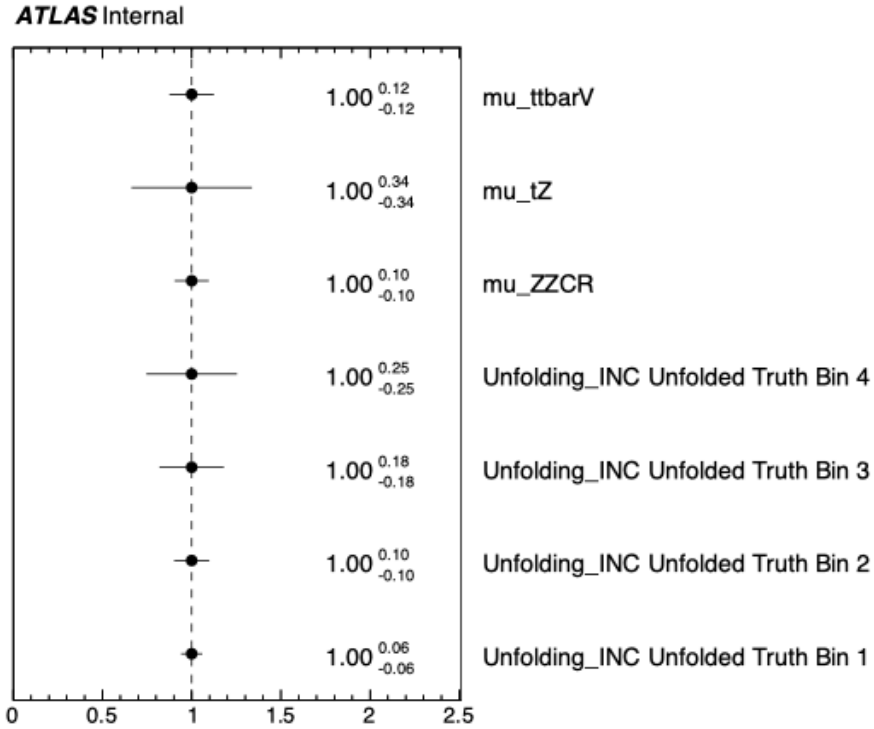
ATLAS Internal



Profile Likelihood Unfolding Method
Asimov measurement for Run2

Profile Likelihood Unfolding Method
Asimov measurement for Run3

Bins (GeV)	$\sigma_{Run2,PLU} (fb)$	$\sigma_{Run3,PLU} (fb)$
$500 < m_{jj} < 700$	$0.75 \pm 0.06 (stat)$	$0.77 \pm 0.06 (stat)$
$700 < m_{jj} < 1000$	$0.56 \pm 0.06 (stat)$	$0.60 \pm 0.06 (stat)$
$1000 < m_{jj} < 1500$	$0.37 \pm 0.05 (stat)$	$0.41 \pm 0.04 (stat)$
$1500 < m_{jj} < 2000$	$0.13 \pm 0.03 (stat)$	$0.15 \pm 0.03 (stat)$
$m_{jj} > 2000$	$0.10 \pm 0.02 (stat)$	$0.12 \pm 0.02 (stat)$



Profile Likelihood Unfolding Method
Asimov measurement for Run2

Profile Likelihood Unfolding Method
Asimov measurement for Run3

Bins (GeV)	σ_{Run2} (fb)	σ_{Run3} (fb)
$N_{jets} = 2$	0.96 ± 0.07 (stat)	1.06 ± 0.06 (stat)
$N_{jets} = 3$	0.65 ± 0.07 (stat)	0.62 ± 0.06 (stat)
$N_{jets} = 4$	0.22 ± 0.05 (stat)	0.26 ± 0.05 (stat)
$N_{jets} \geq 5$	0.08 ± 0.03 (stat)	0.12 ± 0.03 (stat)

Simultaneous Fit

m_{jj}

- Bin 1: $500 < m_{jj} < 1300 \text{ GeV}$
- Bin 2: $1300 < m_{jj} < 2000 \text{ GeV}$
- Bin 3: $m_{jj} > 2000 \text{ GeV}$

N_{jets}

- Bin 1: $N_{jets} = 2$
- Bin 2: $N_{jets} > 2$

BDT

- SR 1: $-1.0 < BDT \text{ score} < -0.6$
- SR 2: $-0.6 < BDT \text{ score} < -0.2$
- SR 3: $-0.2 < BDT \text{ score} < 0.2$
- SR 4: $0.2 < BDT \text{ score} < 0.6$
- SR 5: $0.6 < BDT \text{ score} < 1.0$

$WZjj - EW + WZjj - QCD$

To perform the fit we divide the phase space in the following regions:

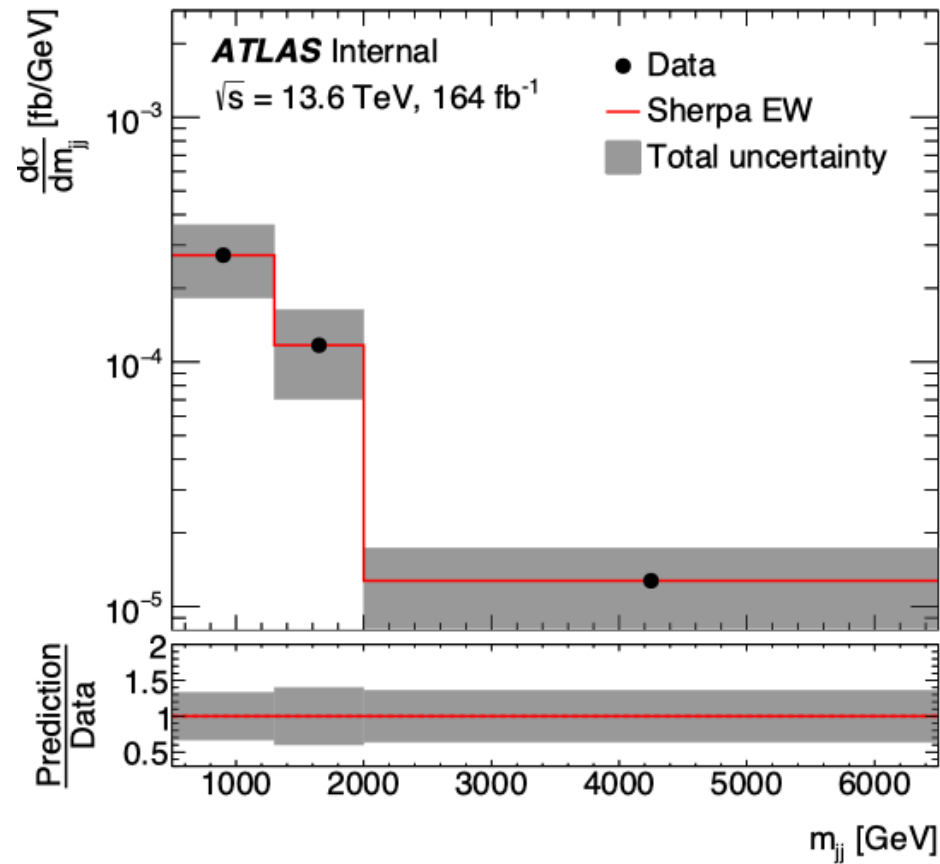
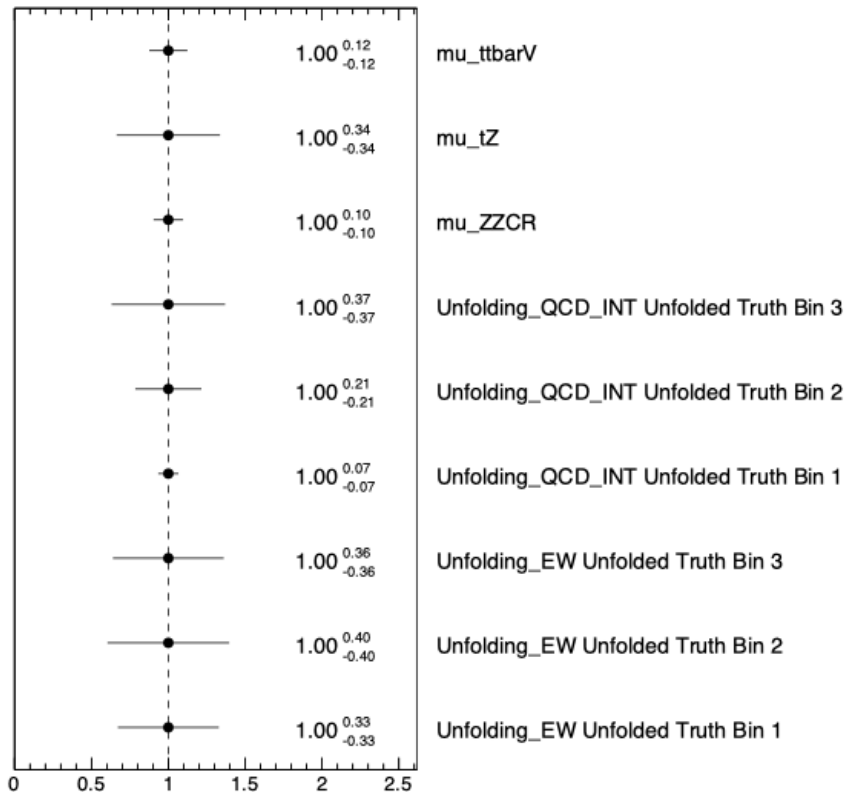
- One WZ VBS Signal Region per BDT bin
 - Region where we expect to have the most signal
 - Achieves maximum separation between processes
- ZZ Control Region
 - Region rich in the ZZ background events
 - Used to constrain the ZZ background
- b CR
 - Region with at least one b-quark jet
 - Used to constrain the background $\bar{t}tV$ and tZ background processes

We introduce scaling factors simultaneously estimated in the SR+CRs:

- $\mu_{truth_bin1}, \dots, \mu_{truth_binN}$ for each unfolded process (EW and QCD+INT)
- $\mu_{ZZ_{QCD}}$ (SRs, ZZCR)
- $\mu_{\bar{t}tV}$ (SRs, ZZCR, b CR)
- μ_{tZ} (SRs, ZZCR, b CR)

**Asimov
Dataset Fit**

ATLAS Internal

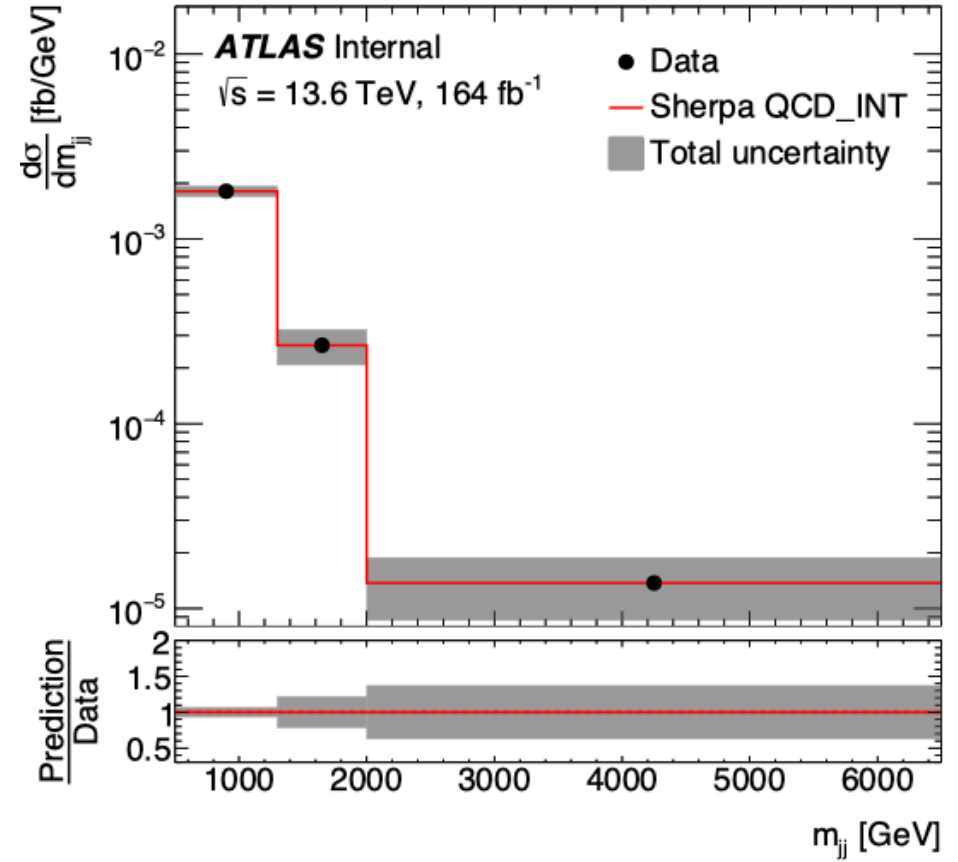
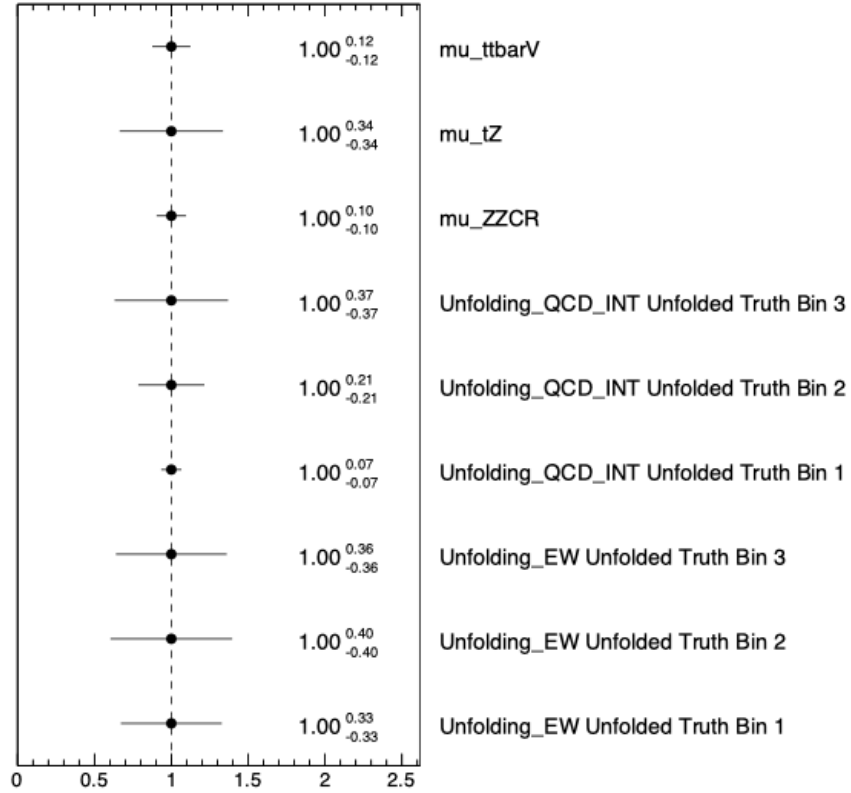


Profile Likelihood Unfolding Method
Asimov measurement for Run2

Profile Likelihood Unfolding Method
Asimov measurement for Run3

Bins (GeV)	$\sigma_{EW,Run2} (fb)$	$\sigma_{EW,Run3} (fb)$
$500 < m_{jj} < 1300$	$0.223 \pm 0.073 (stat)$	$0.218 \pm 0.072 (stat)$
$1300 < m_{jj} < 2000$	$0.089 \pm 0.033 (stat)$	$0.082 \pm 0.033 (stat)$
$m_{jj} > 2000$	$0.062 \pm 0.021 (stat)$	$0.057 \pm 0.021 (stat)$

ATLAS Internal

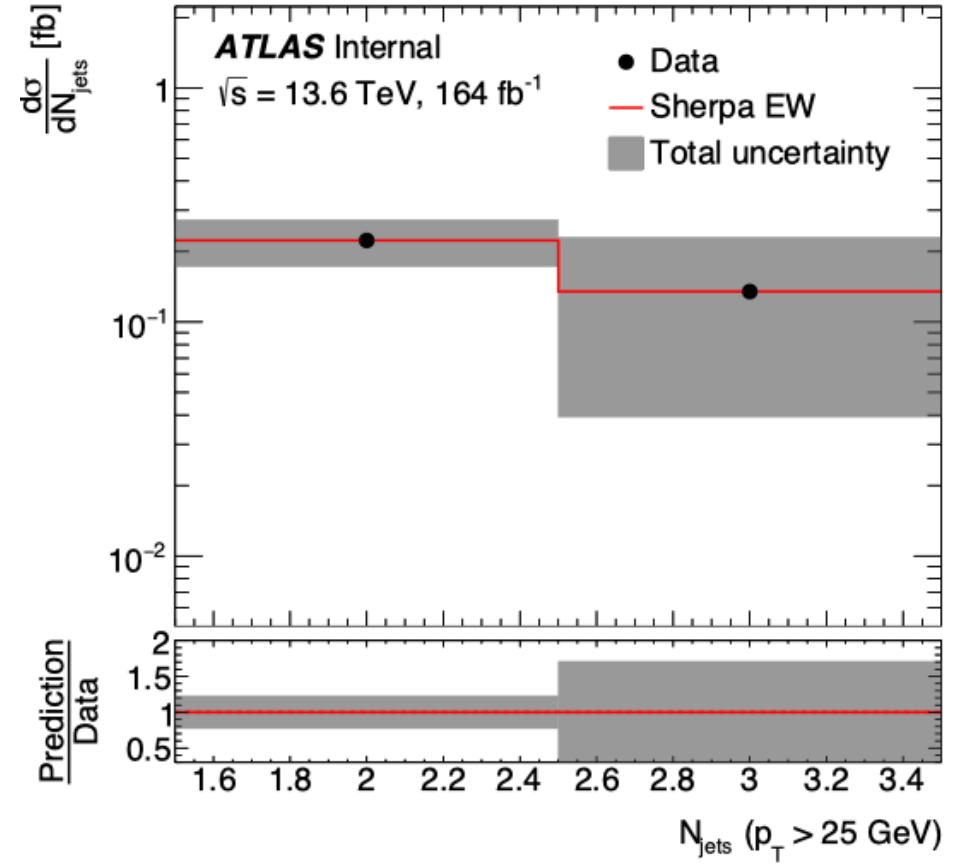
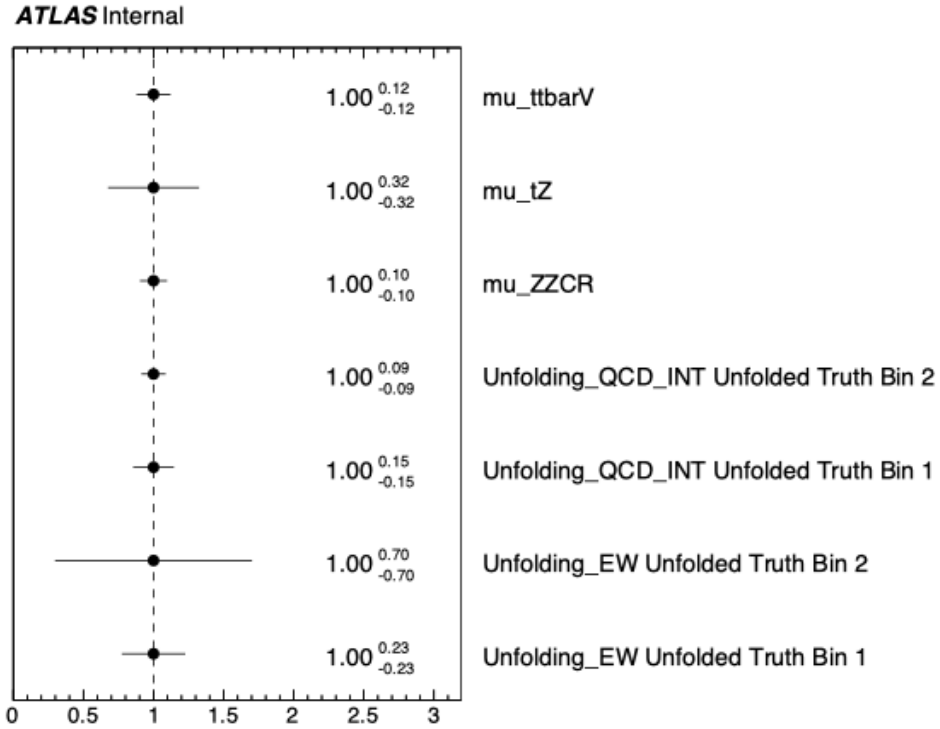


Profile Likelihood Unfolding Method
Asimov measurement for Run2

Profile Likelihood Unfolding Method
Asimov measurement for Run3

Bins (GeV)	$\sigma_{non-EW,Run2}$ (fb)	$\sigma_{non-EW,Run3}$ (fb)
$500 < m_{jj} < 1300$	1.357 ± 0.101 (stat)	1.449 ± 0.096 (stat)
$1300 < m_{jj} < 2000$	0.145 ± 0.038 (stat)	0.186 ± 0.040 (stat)
$m_{jj} > 2000$	0.040 ± 0.023 (stat)	0.062 ± 0.023 (stat)

Asimov EW Fit results

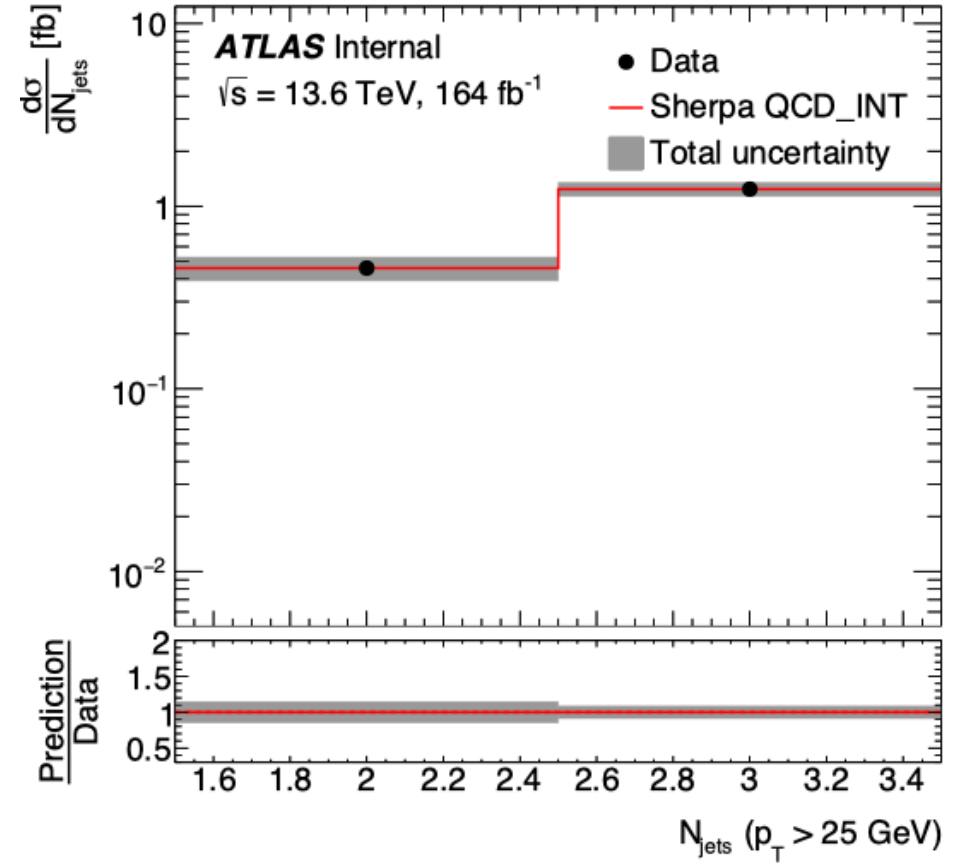
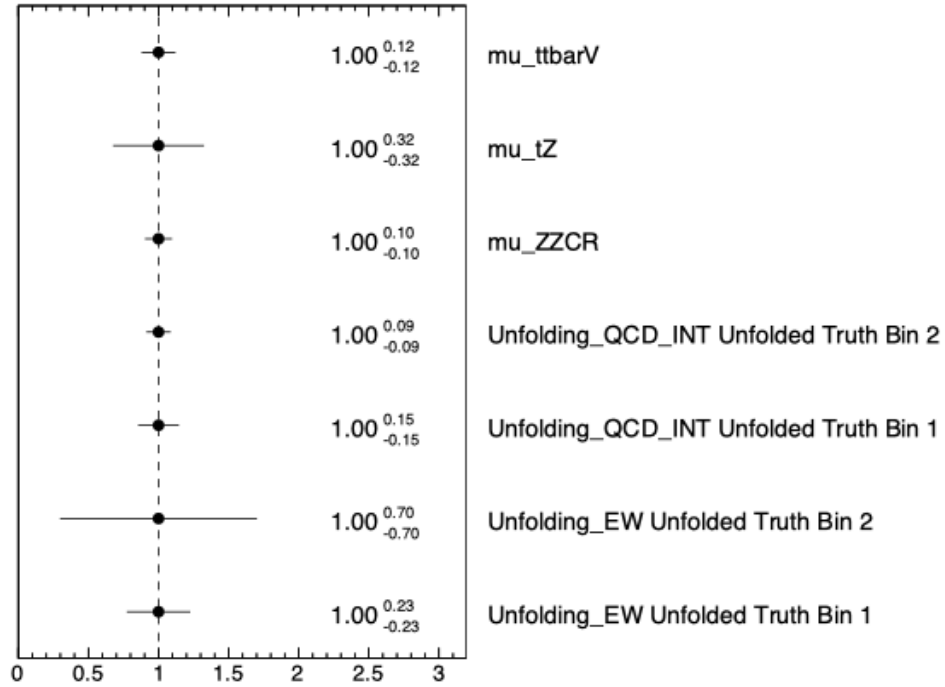


Profile Likelihood Unfolding Method
Asimov measurement for Run2

Profile Likelihood Unfolding Method
Asimov measurement for Run3

Bins (GeV)	$\sigma_{EW,Run2} (fb)$	$\sigma_{EW,Run3} (fb)$
$N_{jets} = 2$	$0.220 \pm 0.051 (stat)$	$0.223 \pm 0.051 (stat)$
$N_{jets} > 2$	$0.154 \pm 0.075 (stat)$	$0.135 \pm 0.096 (stat)$

ATLAS Internal



Profile Likelihood Unfolding Method
Asimov measurement for Run2

Profile Likelihood Unfolding Method
Asimov measurement for Run3

Bins (GeV)	$\sigma_{non-EW,Run2}$ (fb)	$\sigma_{non-EW,Run3}$ (fb)
$N_{jets} = 2$	0.406 ± 0.064 (stat)	0.458 ± 0.067 (stat)
$N_{jets} > 2$	1.135 ± 0.099 (stat)	1.239 ± 0.108 (stat)