



Partial Run 3 WW measurement and EFT constrain

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Phase space

Event selection
Exactly 2 opposite-charged leptons ($1e$ and 1μ), $p_T > 27$GeV $\lvert\eta(e)\rvert \leq 2.47$ with crack veto $1.37 \leq \lvert\eta(e)\rvert \leq 1.52$ $\lvert\eta(\mu)\rvert \leq 2.5$
Electrons: ID: TightLH, Isol: Tight_VarRad Muons: ID: Medium, Isol: PFlowTight_VarRad
$\lvert d_0/\sigma_{d_0}\rvert < 5(e),\ 3(\mu), \lvert z_0 \cdot \sin\theta\rvert < 0.5$ mm
No additional electron with: $p_T > 10$ GeV, $\lvert\eta\rvert \leq 2.47$, ID: LooseBLayerLH, Isol: Loose_VarRad
No additional muon with: $p_T > 10$ GeV, $\lvert\eta\rvert \leq 2.5$, ID: Loose, Isol: NonIso
Inclusive in jet multiplicity for $p_T(j) > 30$ GeV and $\lvert\eta(j)\rvert \leq 4.5$ JVT and fJVT applied N_{b-jets} @90% eff. (GN2 PCBT > 1) = 0
$m_{e\mu} > 100$ GeV Veto on non-prompt leptons

Table 4.4: Summary of the event selection

Fiducial selection is basically same,
Except no electron crack veto, and OR is ΔR lepton veto

Sample	Yields ± Stat.
WW	69 729.5 ± 84.8
$Z \to \tau\tau$	8592.1 ± 586.5
Fakes (DD)	9913.8 ± 99.6
WZ	2887.5 ± 10.2
VV	179.3 ± 1.4
$t\bar{t}$ (DD)	87 991.9 ± 296.4
$V\gamma$	260.2 ± 29.8
$W + jets$	119.8 ± 64.8
VVV	232.2 ± 0.5
VV EWK	878.1 ± 9.7
Single-top	22 799.9 ± 31.0
Total mc23ade	203 580.4 ± 607.6
Run 3 Data	206 415.0 ± 454.3
Data/MC	1.01

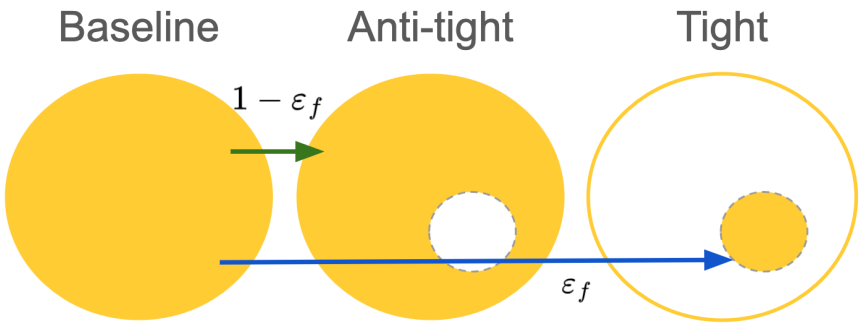
- Using 2022 ~ 2024 data recorded with single lepton trigger.
- Compared to Run 2 analysis
  m_{ll} cut increase from 85 GeV to 100 GeV.
- $t\bar{t}$ background estimated with b-tag counting method.
- Other prompt background is estimated using MC.
- Reducible background estimated with matrix method.

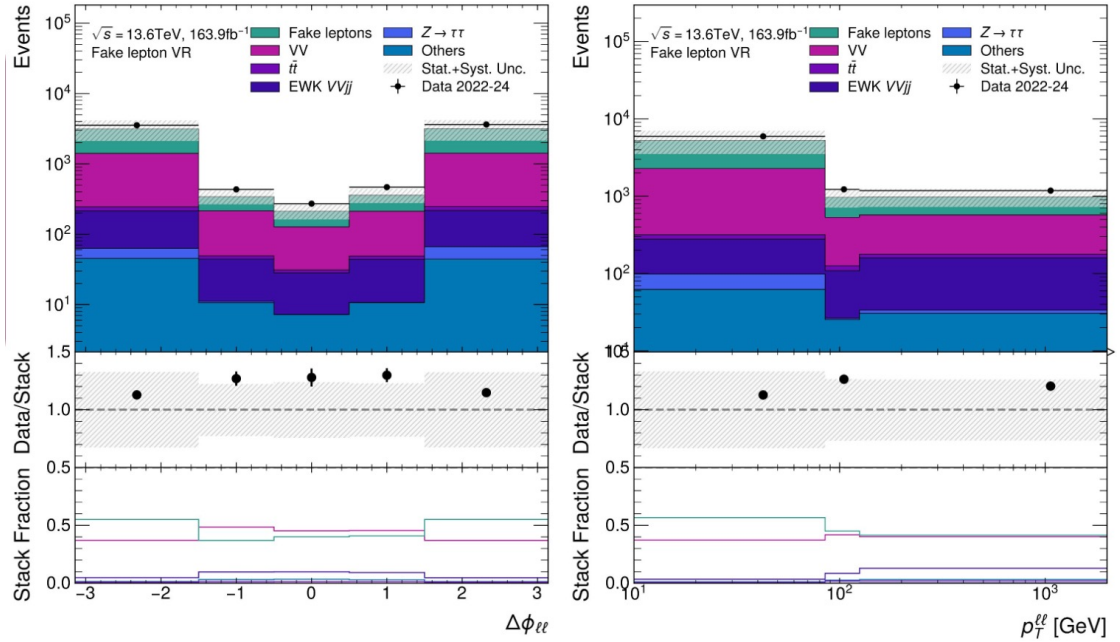
Irreducible background

$$N^t = \varepsilon_r N_r^b + \varepsilon_f N_f^b$$
$$N^{!t} = (1-\varepsilon_r) N_r^b + (1-\varepsilon_f) N_f^b$$

$$\begin{pmatrix} N^t \\ N^{!t} \end{pmatrix} = \begin{pmatrix} \varepsilon_r & \varepsilon_f \\ 1-\varepsilon_r & 1-\varepsilon_f \end{pmatrix} \begin{pmatrix} N_r^b \\ N_f^b \end{pmatrix}$$

$$N_f^b = \frac{1}{\varepsilon_r - \varepsilon_f}\left[(\varepsilon_r - 1)N^t + \varepsilon_r N^{!t}\right] \rightarrow N_f^t = \varepsilon_f N_f^b$$

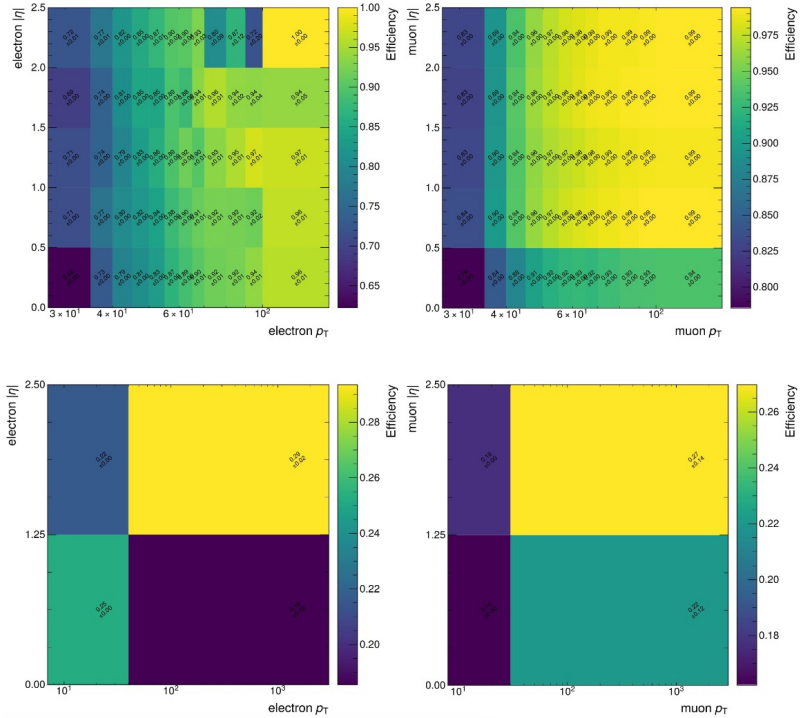




ε_r in Z peak region using tag probe to MC
ε_r in Z peak with additional baseline lepton region using tag probe to data.

$$\varepsilon_r = \frac{N^t_{probe,r}}{N^t_{probe,r} + N^{!t}_{probe,r}}$$

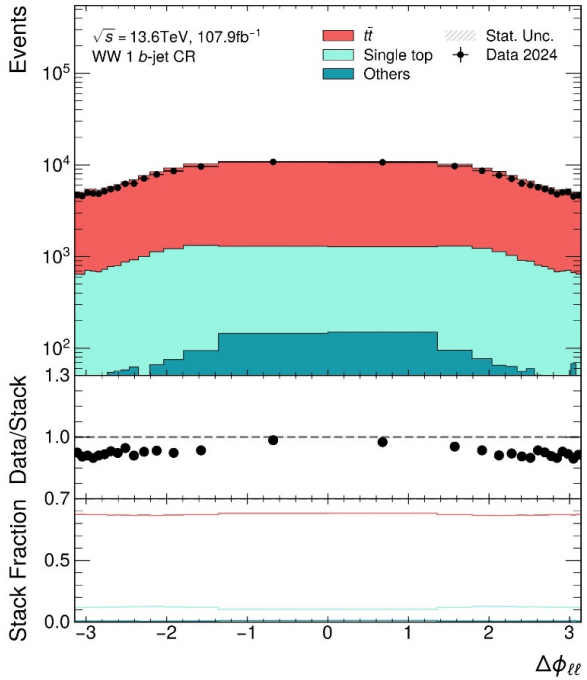
$$\varepsilon_f = \frac{\left(N^t_{probe} - N^t_{probe,r}\right)}{\left(N^{!t}_{probe} - N^{!t}_{probe,r}\right) + \left(N^t_{probe} - N^t_{probe,r}\right)}$$



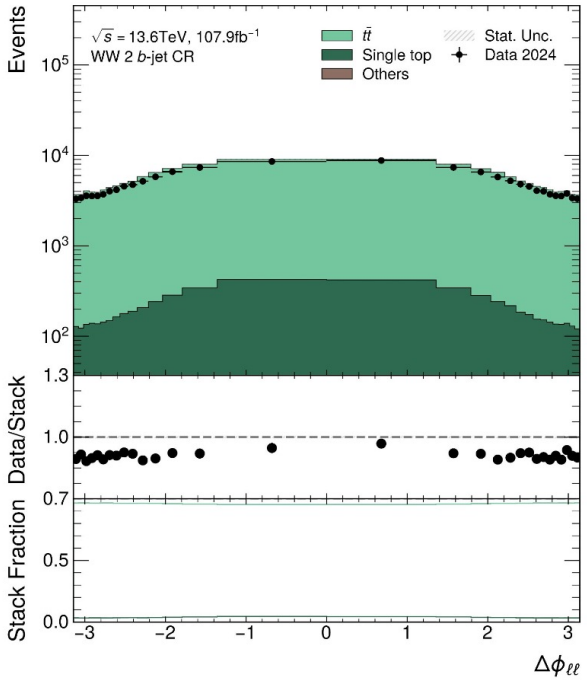
- Slightly underestimate in the VR.
- But still within systematic uncertainty.

$t\bar{t}$ background

$$N_{1b}^{t\bar{t}} = N_{1b} - N_{1b}^{!t\bar{t}} = N_{\geq 0b}^{t\bar{t}} \cdot 2\varepsilon_b(1 - C_b\varepsilon_b)$$



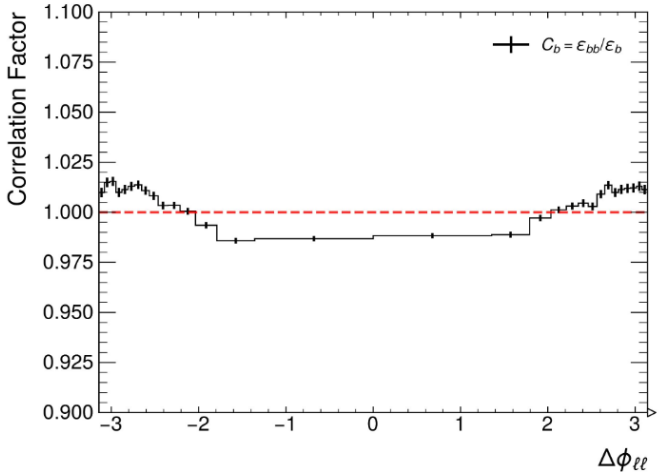
$$N_{2b}^{t\bar{t}} = N_{2b} - N_{2b}^{!t\bar{t}} = N_{\geq 0bb}^{t\bar{t}} \cdot C_b\varepsilon_b^2$$

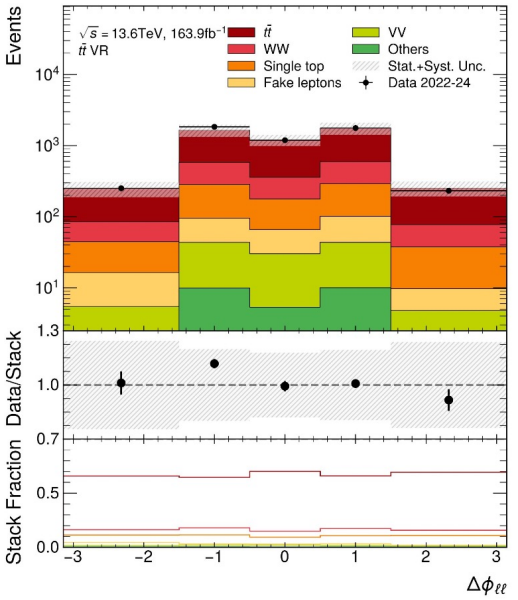


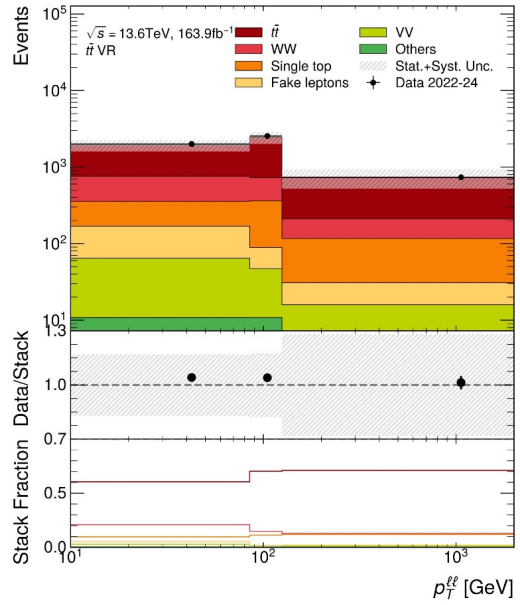
$$N_{0b}^{t\bar{t}} = N_{\geq 0b}^{t\bar{t}} - N_{1b}^{t\bar{t}} - N_{2b}^{t\bar{t}}$$

$$N_{0b}^{t\bar{t}} = \frac{C_b}{4} \frac{\left(N_{1b}^{t\bar{t}} + 2N_{2b}^{t\bar{t}}\right)^2}{N_{2b}^{t\bar{t}}} - N_{1b}^{t\bar{t}} - N_{2b}^{t\bar{t}}$$

$$C_b = \frac{4 \cdot N_{\geq 0b,MC}^{t\bar{t}} N_{2b,MC}^{t\bar{t}}}{\left(N_{MC,1b}^{t\bar{t}} + 2N_{MC,2b}^{t\bar{t}}\right)^2}$$

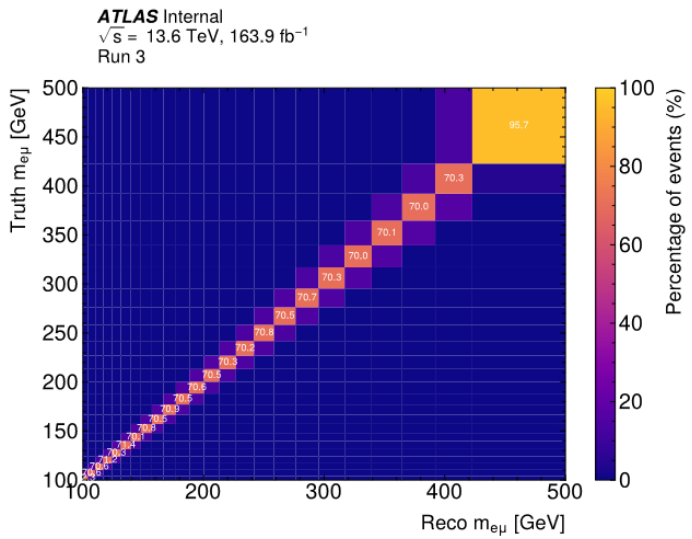


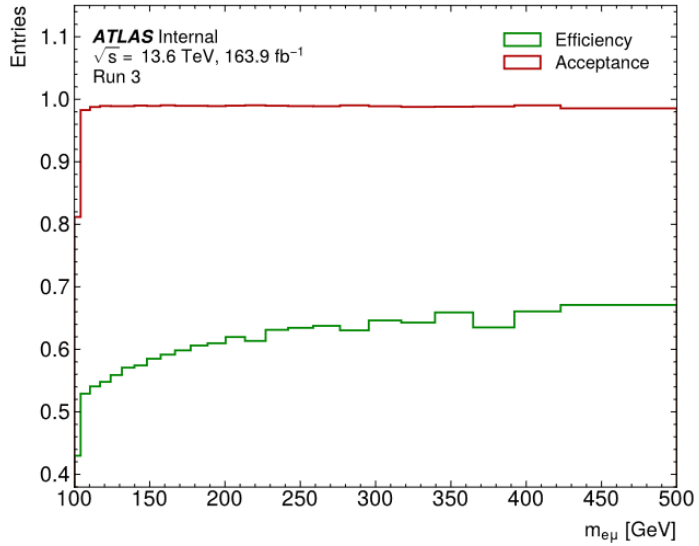


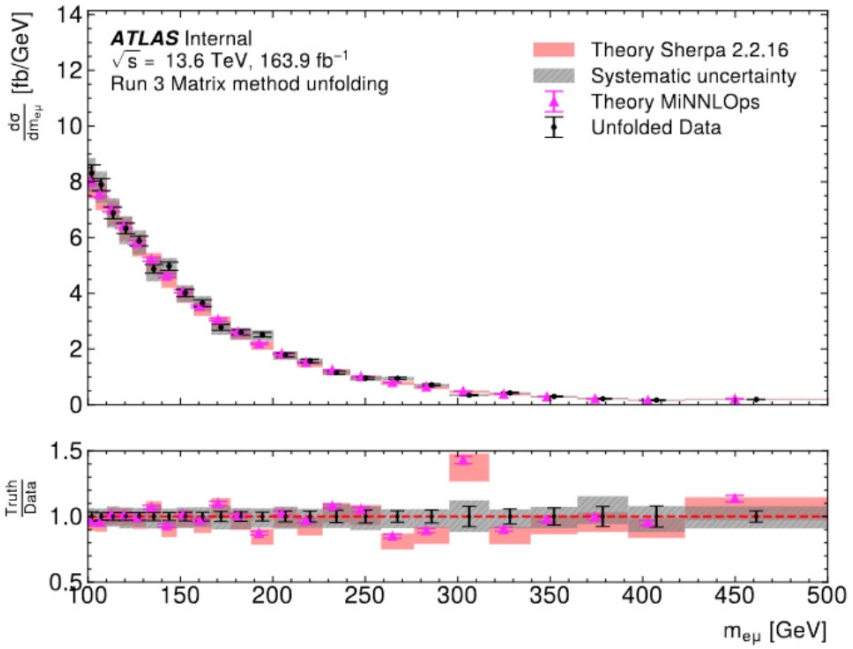


- b-tag counting method is used.
- It found good agreement within the VR.

Unfolding

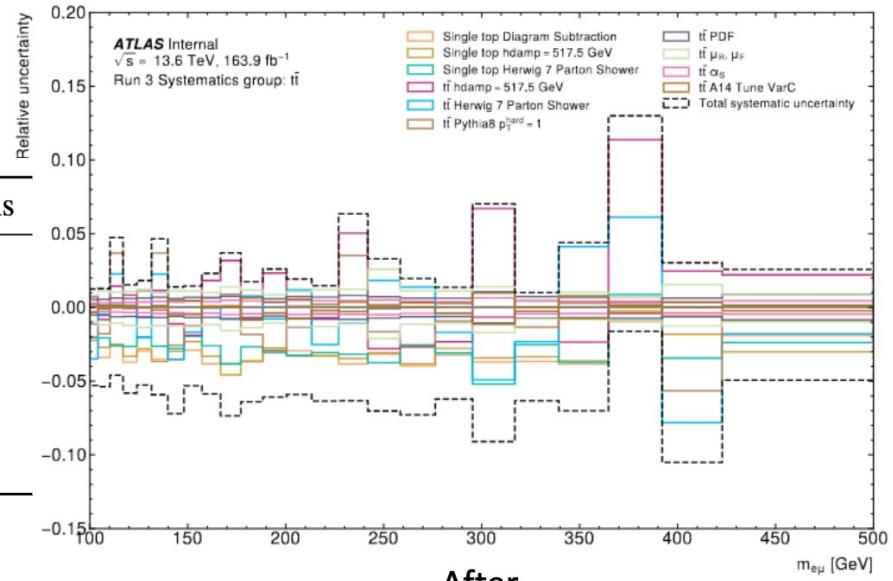






- Iterative Bayesian Unfolding (IBU) is used for unfolding.
- Closure test is performed to validate the unfolding procedure.
- 5 1D distribution and 1 2D distribution is extracted.

Variable	Number of iterations
$p_T(\ell_1)$	3
$m(e,\mu)$	3
$p_T(e,\mu)$	3
$\Delta\phi(\ell,\ell)$	2
$\Delta\eta(\ell,\ell)$	2
$\Delta\phi(\ell,\ell) \times p_T(e,\mu)$	2



After

EFT interpretation

- Profile likelihood ratio is used to estimate the confidence intervals for a Wilson coefficient. Using binned unfolded data, and including all systematic and data statistic are considered .

$$L(\mathbf{x} \mid \mathbf{c}, \boldsymbol{\theta}) = \frac{1}{\sqrt{(2\pi)^{n_{\text{bins}}} \det(V)}} \exp\left(-\frac{1}{2}\Delta\mathbf{x}^{\top}(\mathbf{c}, \boldsymbol{\theta})\, V^{-1}\, \Delta\mathbf{x}(\mathbf{c}, \boldsymbol{\theta})\right) \times \prod^{n_{\text{theo syst}}} f_i(\theta_{\text{theo syst},i}) \times \prod^{n_{\text{exp syst}}} f_i(\theta_{\text{exp syst},i})$$

Wilson coefficient	fitted variable	95% CL linear only	95% CL linear+quad
cW	mll	[-5.06,5.95]	[-0.27,0.27]
	ll_pT	[-3.19,3.88]	[-0.28,0.28]
	pT_ll	[-2.26,2.92]	[-0.30,0.30]
	dEta_ll	[-9.55,8.29]	[-0.54,0.55]
	dPhi_ll	[-1.74,1.71]	[-0.42,0.55]
cHWB	mll	[-90.43,89.93]	[-4.67,4.71]
	ll_pT	[-25.50,24.07]	[-5.28,5.78]
	pT_ll	[-33.10,33.48]	[-13.78,11.06]
	dEta_ll	[-29.53,28.31]	[-7.69,8.71]
	dPhi_ll	[-90.28,89.85]	[-6.54,6.49]
$c\tilde{W}$	mll	[-17.18,17.98]	[-0.27,0.27]
	ll_pT	[-20.74,21.89]	[-0.28,0.28]
	pT_ll	[-17.45,18.12]	[-0.30,0.30]
	dEta_ll	[-23.97,24.27]	[-0.54,0.54]
	dPhi_ll	[-0.84,0.80]	[-0.45,0.44]
$cH\tilde{W}B$	mll	[-291.84,299.14]	[-4.80,4.81]
	ll_pT	[-189.35,193.80]	[-5.28,5.32]
	pT_ll	[-224.69,224.32]	[-6.36,6.32]
	dEta_ll	[-159.26,161.49]	[-6.77,6.81]
	dPhi_ll	[-4.00,3.79]	[-3.79,3.64]

Reference	Wilson coefficient	95% CL linear only	95% CL linear+quad with cross terms	95% CL linear+quad no cross terms
ATLAS global EFT fits Run 2 [67]	cW	[-1.5,2.5]	-	[-1.6,1.1]
	cHWB	[-3.2,1.9]	-	[-3.5,1.1]
Full Run 2 WW measurement[1]	cW	[-3.5,3.4]	[-0.18,0.18]	-
	cHWB	[-10,8]	[-1.7,1.9]	-
Full Run 2 Wγ measurement[68]	cW	[-0.28, 0.21]	-	[-0.05, 0.05]
	cHWB	[-1.09, 0.50]	-	[-0.58, 0.38]
	$c\tilde{W}$	[-0.45, 0.14]	-	[-0.54, 0.11]
	$cH\tilde{W}B$	[-0.31, 0.07]	-	[-0.31, 0.07]
Full Run 2 $W^{\pm}Z$ measurement[69]	cW	[-1.150, 0.181]	-	[-0.093, 0.079]
	cHWB	[-0.470, 1.440]	-	[-0.458, 1.520]
	$c\tilde{W}$	[-1.625, 1.332]	-	[-1.505, 1.263]
	$cH\tilde{W}B$	[-0.186, 0.139]	-	[-0.109, 0.093]

- First $c_{\tilde{W}}$ and $c_{H\tilde{W}B}$ limits from a WW Measurement.
- Better expected linear-only limits on c_W than the Run 2 WW measurement.
- ML based observable is under development.

Contribution from USTC

- We focus on the precise modeling for the SM process.
  - Migrate MiNNLOps generator into ATLAS Athena framework,
    prepare and validate the NNLO Monte Carlo prediction for the quark initiate WW process.
  - Prepare and validate the NLO Monte Carlo prediction for the gluon loop-initiate WW process.
  - Provide precise fixed order calculation with MATRIX,
    NNLO QCD and NLO EW for the quark initiate WW process.
    NLO QCD gluon loop-initiate WW process.
    LO γ initiate WW process.
  - Provide alternative framework to cross-check the cutflow and event selection.
- R&D on the polarization study.
  - Migrate NLO polarization generator into ATLAS Athena framework,
    Prepare and validate the NLO polarized sample.
  - Migrate EFT polarization generator into ATLAS Athena framework,
    Get ready for the future EFT study with polarization diboson probe.
  - Machine learning study on the reco-level signal-background discrimination.
  - Statistic only fit, significance extraction.

Outlook

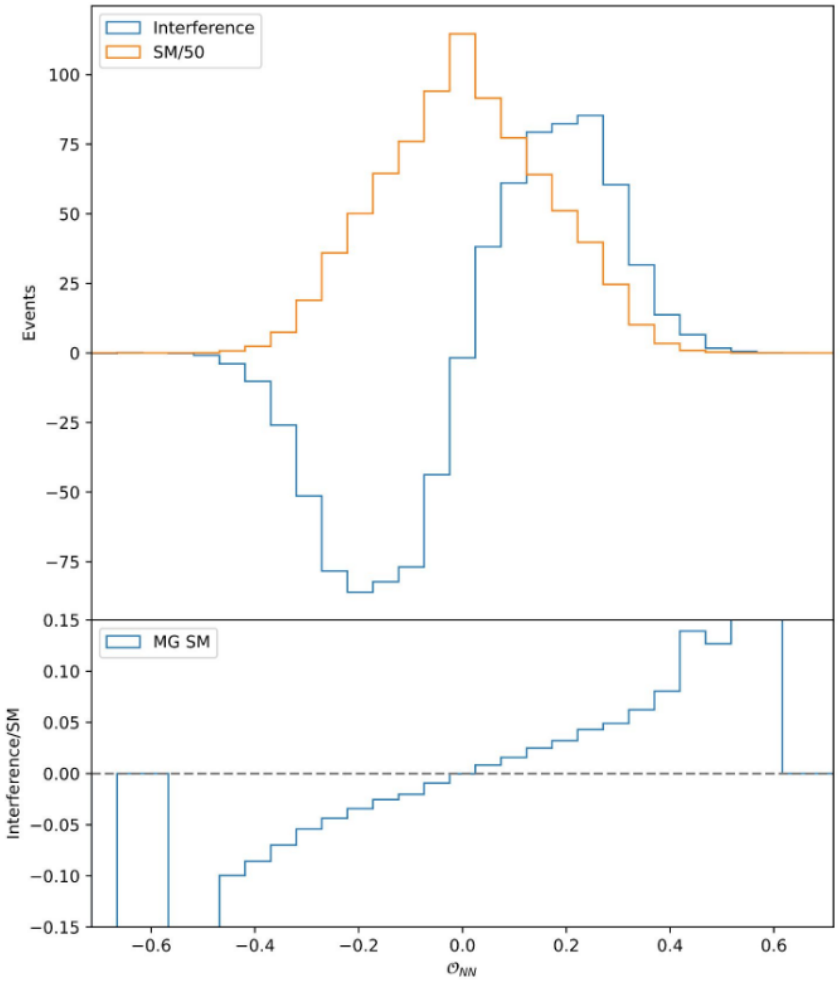
- For the WW measurements, we are now working on addressing action item from EB.
  - Further check on the underestimate for the non-prompt estimation.
  - Further check on the jet pile-up related systematic.
  - Including the MATRIX prediction into comparison.
  - Check other observable for the 2D unfolding m_{ll}, m_{Tll}.
- Unfolded ONN is ready for the EFT interpretation.
- The analysis is expected to be finalized within coming month.
  The paper is expected to be ready early next year.

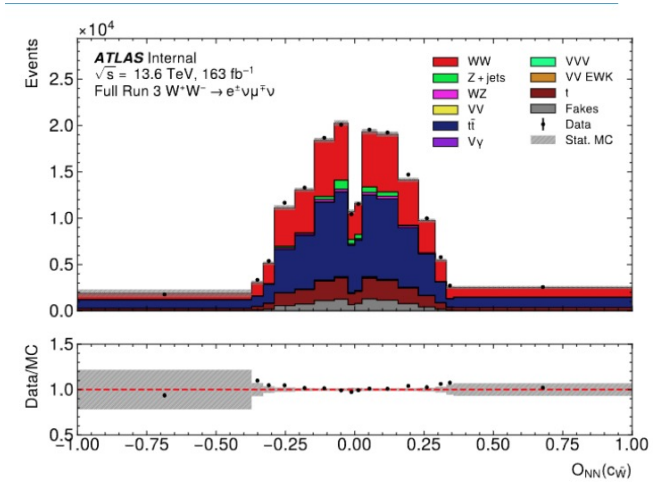
- We plan to present preliminary polarization study and kick off analysis in the near future.
  - The polarization of osWW shows unique sensitivity to the initial state with heavy flavor quark.
  - The polarization fraction also shows the sensitivity to the EFT operator.

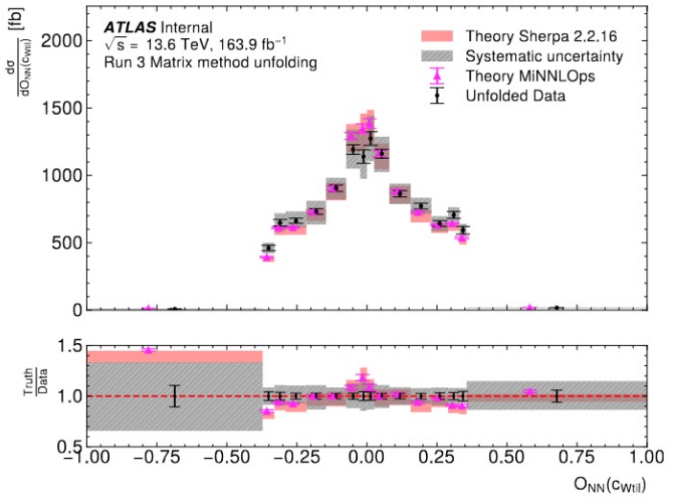
Thanks for your attention!

Backup

ONN observable







- ML based CP sensitive observable

$$O_{NN} = P_+ - P_-$$

- Model is trained to separate three categories.

