ATLAS EXPERIMENT

VBF and VBS Measurements in ATLAS

Zhen Wang

Tsung-Dao Lee Institute

On behalf of the ATLAS Collaboration

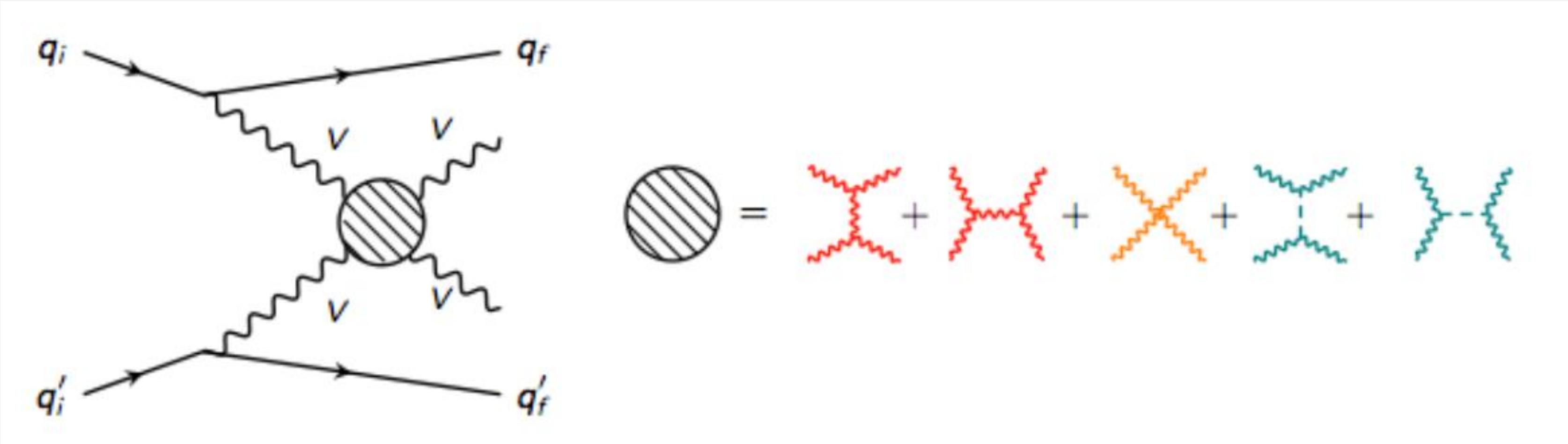
PASCOS 2024

李政道研究所
TSUNG-DAO LEE INSTITUTE

2024/July/10

Motivation

- Vector boson fusion (VBF) and vector boson scattering (VBS) are direct probes of boson interactions, both in standard model and beyond

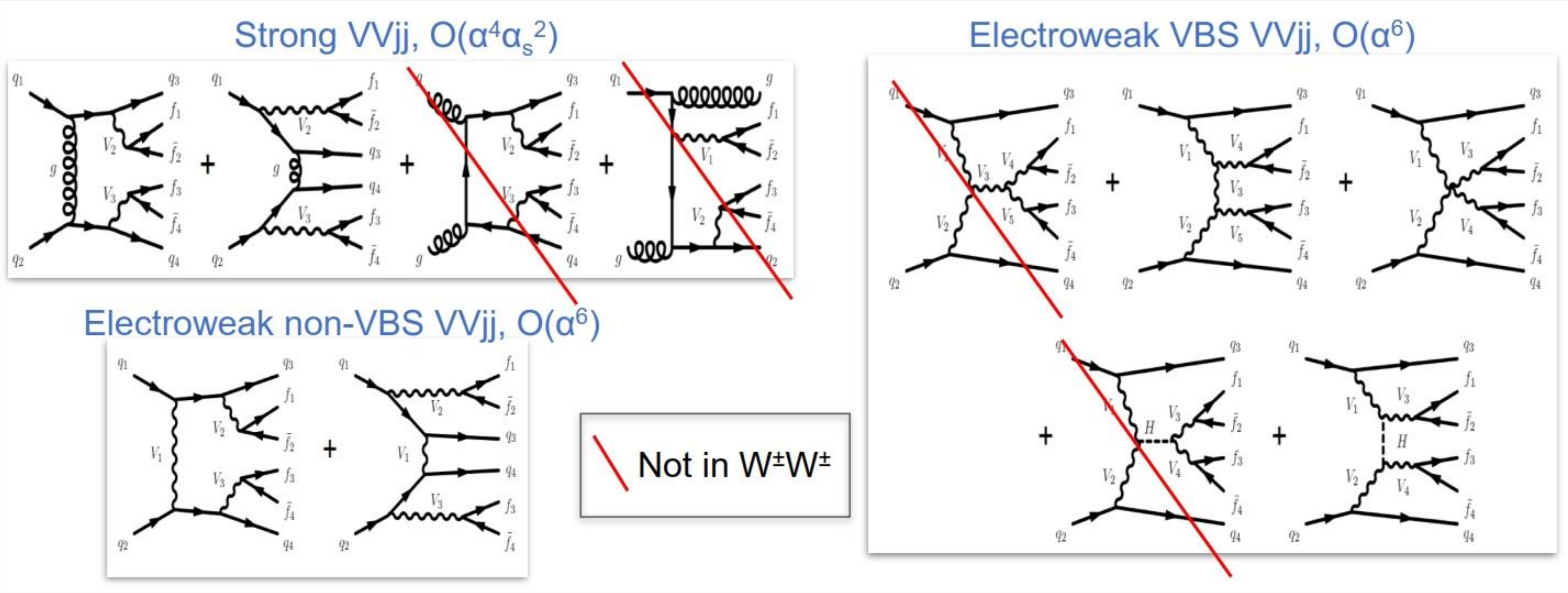


- VBS allows to test SM predictions to triple and quartic gauge couplings

- Topics in this talk: same-sign $W^{\pm}W^{\pm}jj$, opposite sign $W^{+}W^{-}jj$, differential $ZZjj$, VBS $W\gamma jj$, VBS $WZjj$

Same-sign $W^{\pm}W^{\pm}jj$

- Motivation:
  - Massive vector boson scattering (VBS) probes mechanism of electroweak symmetry breaking (EWSB) in the Standard Model (SM)
  - Unique sensitivity for new physics phenomena



- $\boldsymbol{W^{\pm}W^{\pm}jj}$ final states has largest EW to QCD xsection ratio because of the suppression of QCD-induced background
- EW measures both VBS and non-VBS process, inclusive measurements include EW + QCD + interference

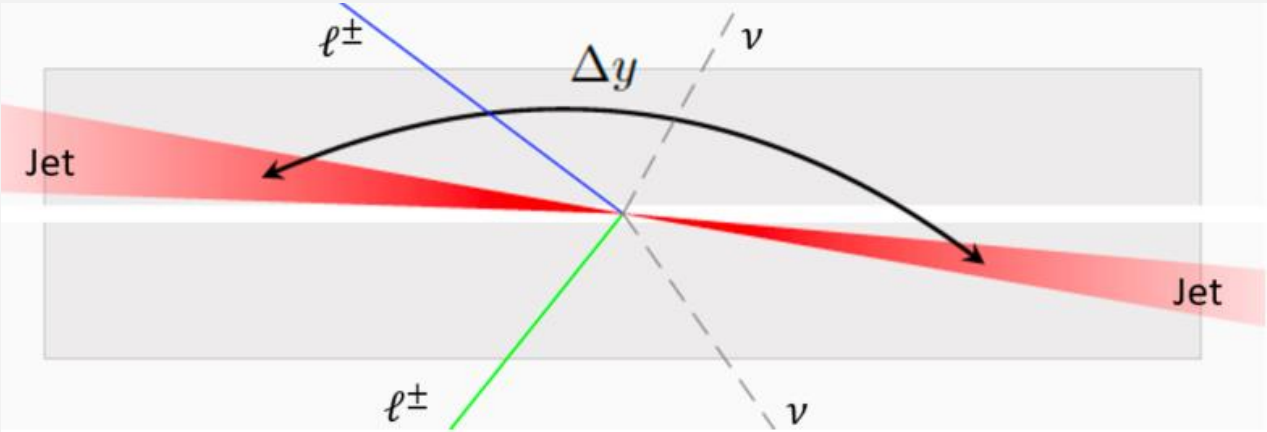
Same-sign $W^{\pm}W^{\pm}jj$ Strategy

李政道研究所
TSUNG-DAO LEE INSTITUTE

- SR selections:
  - Two isolated same-sign leptons with transverse momentum $p_T > 27\ GeV$
  - Large missing energy due to presence of neutrinos $E_T^{miss} > 30\ GeV$
  - Jet transverse momentum $p_T^{leading} > 65\ GeV$ $p_T^{sub-leading} > 30\ GeV$ and b-veto
  - VBS signature: $m_{jj} > 500\ GeV$ & $|\Delta y_{jj}| > 2$

- WZ CR (improve modelling from QCD-induced $W^{\pm}Zjj$ events):
  - One more lepton with $p_T > 15\ GeV$
  - $m_{jj} > 200\ GeV$ & $m_{lll} > 106\ GeV$ (suppress radiative Z decay)

- Low-m_{jj} CR (control uncertainties of major background in signal extraction fit):
  - $200\ GeV < m_{jj} < 500\ GeV$



- Backgrounds modelled with MC and data-driven method:
  - $WZ/\gamma^{*}jj$
  - Non-prompt lepton & lepton charge mis-identification
  - Remaining background…

Same-sign $W^{\pm}W^{\pm}jj$ Fiducial Cross Section

李政道研究所 TSUNG-DAO LEE INSTITUTE

- Fiducial region defined as closely as possible to the analysis selections
- Separate maximum likelihood fits with free parameter μ_{sig}^{EW} ($\mu_{sig}^{EW+Int+QCD}$) performed to measure the EW and inclusive cross sections. $\mu^{QCD\,WZ}$ used as normalization coefficient for QCD $W^{\pm}Zjj$
- SR and CRs are split into four regions depending on lepton flavors : ee, $e\mu, \mu e, \mu\mu$

Description	$\sigma_{\text{fid}}^{\text{EW}}$ [fb]	$\sigma_{\text{fid}}^{\text{EW+Int+QCD}}$ [fb]
Measured cross section	2.92 ± 0.22 (stat.) ± 0.19 (syst.)	3.38 ± 0.22 (stat.) ± 0.19 (syst.)
MG5_aMC+Herwig7	2.53 ± 0.04 (PDF) $^{+0.22}_{-0.19}$ (scale)	2.92 ± 0.05 (PDF) $^{+0.34}_{-0.27}$ (scale)
MG5_aMC+Pythia8	2.53 ± 0.04 (PDF) $^{+0.22}_{-0.19}$ (scale)	2.90 ± 0.05 (PDF) $^{+0.33}_{-0.26}$ (scale)
Sherpa	2.48 ± 0.04 (PDF) $^{+0.40}_{-0.27}$ (scale)	2.92 ± 0.03 (PDF) $^{+0.60}_{-0.40}$ (scale)
Sherpa ⊗ NLO EW	2.10 ± 0.03 (PDF) $^{+0.34}_{-0.23}$ (scale)	2.54 ± 0.03 (PDF) $^{+0.50}_{-0.33}$ (scale)
Powheg Box+Pythia	2.64	–

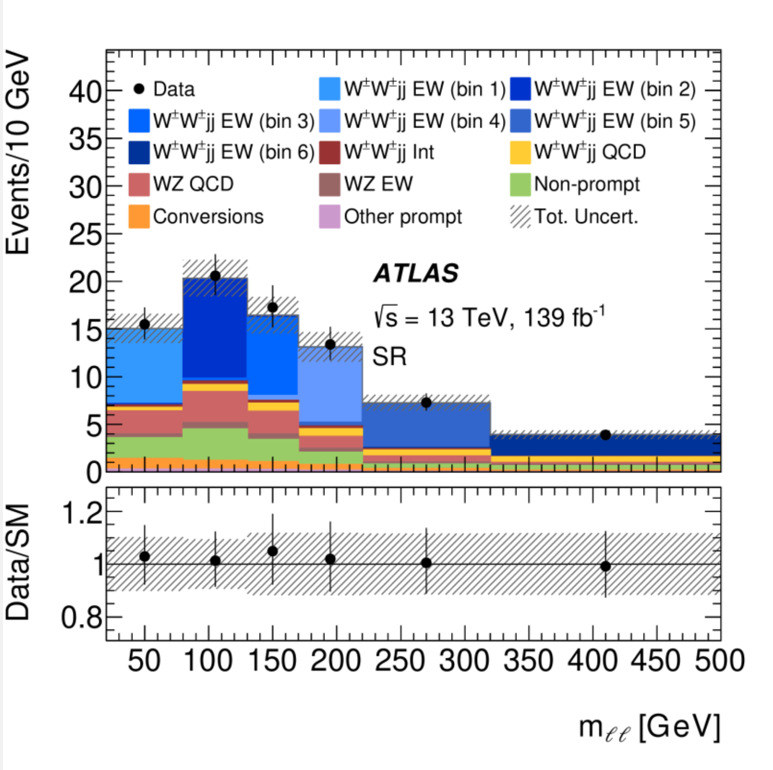
- Predictions agree with the observed data within uncertainties generally
- Observed cross section is slightly higher than predicted cross section

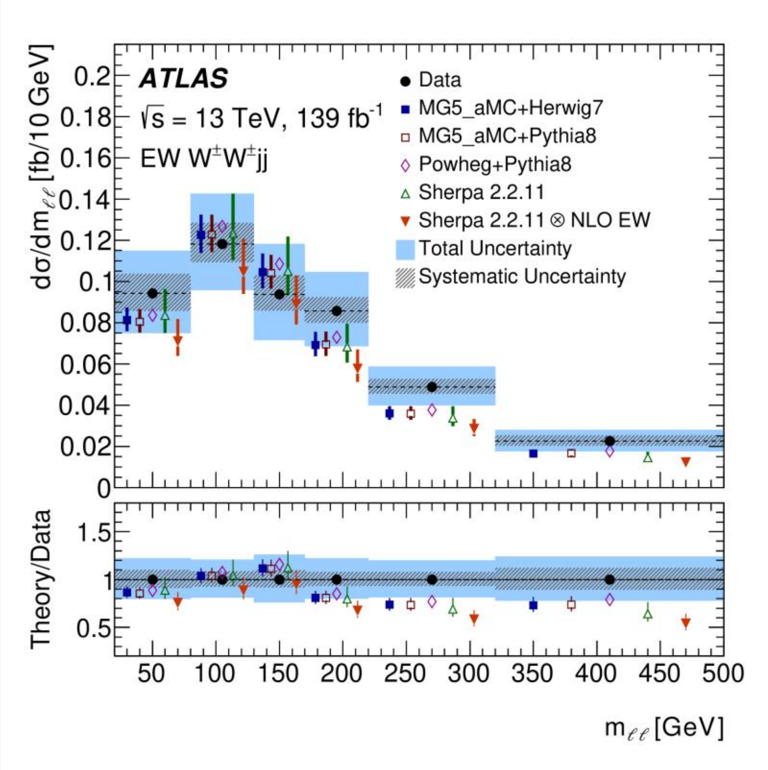
Same-sign $W^{\pm}W^{\pm}jj$ Differential Cross Section

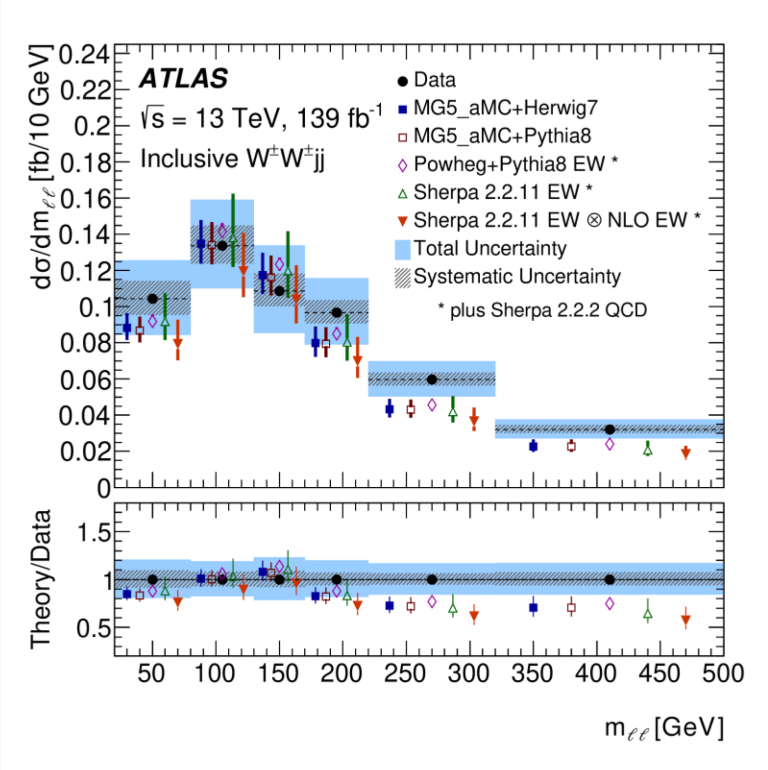
$$m_T = \sqrt{\left(E_T^{\ell\ell} + E_T^{\text{miss}}\right)^2 - \left|\vec{p}_T^{\,\ell\ell} + \vec{E}_T^{\text{miss}}\right|^2}$$

$$\xi_{j3} = \left|\frac{\eta_{j3} - \frac{1}{2}(\eta_{j1} + \eta_{j2})}{\eta_{j2} - \eta_{j1}}\right|$$

- Same fiducial space is used for extraction of differential cross section
- A maximum-likelihood fit is performed to do the cross section unfolding
- Five observables $m_{ll}, m_T, m_{jj}, N_{gapjets}$ *and* ξ_{j3} are studied



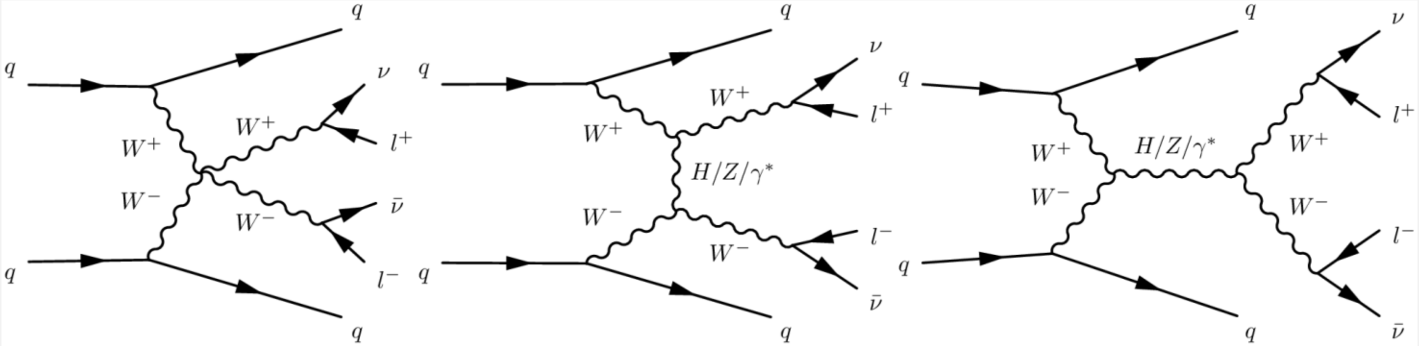




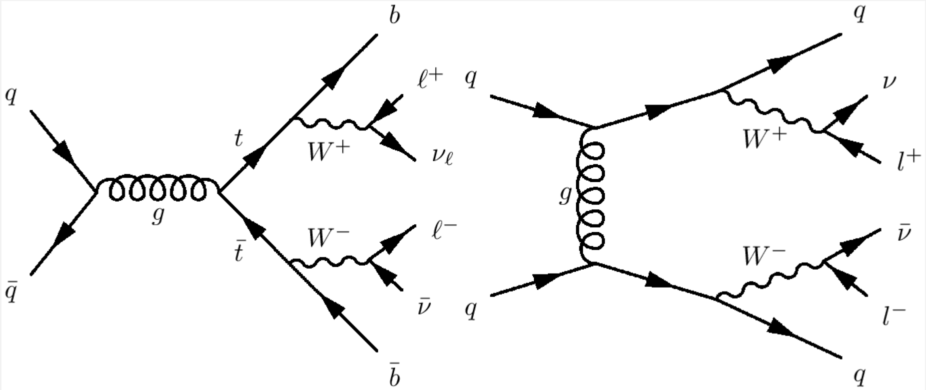
- Prediction underestimates data but is in good agreements within uncertainties

Opposite-sign W^+W^-jj

- First observation of EW W^+W^-jj in ATLAS
- Opposite-sign W^+W^-jj has small cross sections and large background contributions
- Two neural networks trained to separate signal from $t\bar{t}$ and Strong W^+W^-jj backgrounds
- Interesting events should contain two leptons, two or three jets and missing transverse energy



EW W^+W^-jj



$t\bar{t}$ and Strong W^+W^-jj

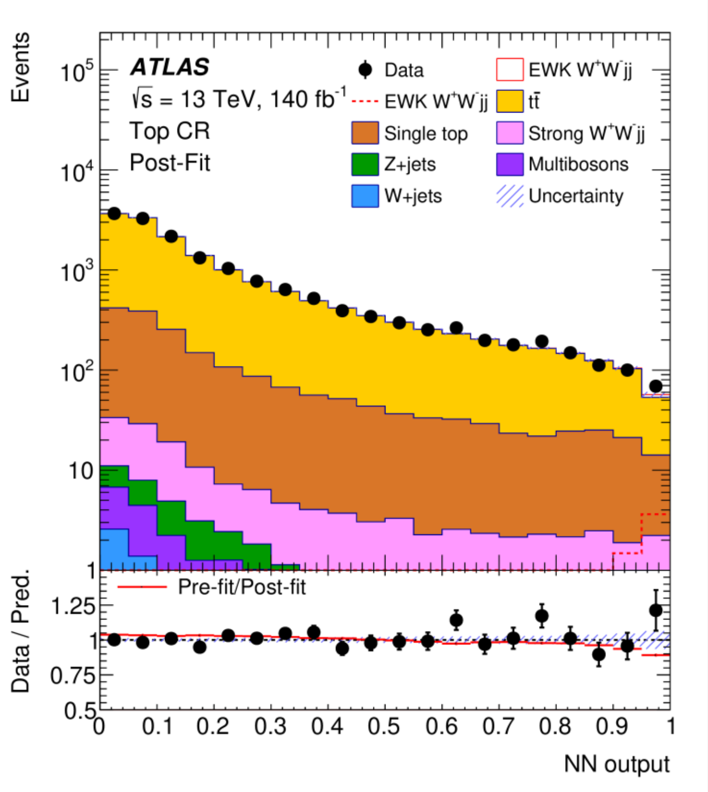
Opposite-sign W^+W^-jj Strategy

- One signal region, one control region to constrain top backgrounds

- Apply cuts before the neural network training:
  - Two opposite sign tight isolated leptons with $p_T > 27\ GeV$ (one electron one muon) and third lep veto
  - $p_T^{miss} > 15\ GeV$ and two or three jets with $p_T > 25\ GeV$
  - Centrality cuts to improve NN performance, $m_{ll} > 80\ GeV$ to suppress VBF HWW backgrounds
  - B-jet veto in SR and b-tag (one of the two leading jets) in CR

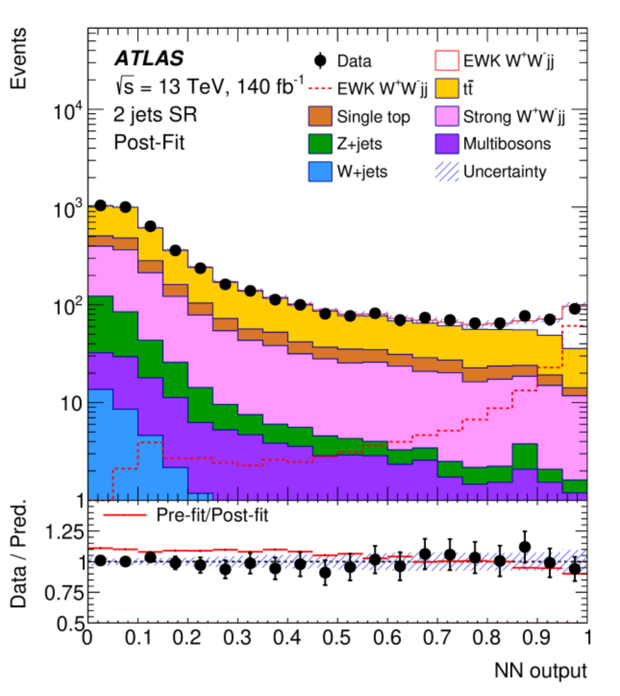
- Two NNs for two-jet and three-jet cases in SR, validation checks performed in low NN-score region (<0.6) on:
  - DATA/MC agreement and correlations between variables

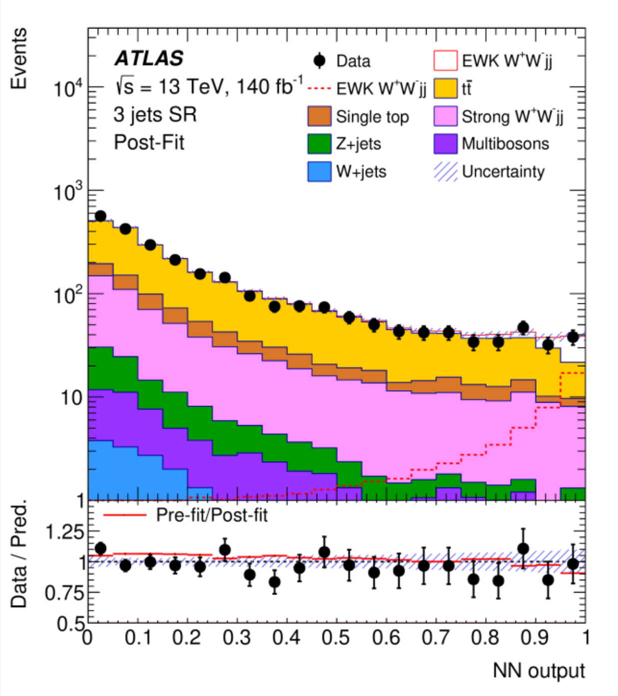
- Uncertainty estimations:
  - Experimental uncertainties: jet energy scale, b-tagging efficiency, jet flavor composition and jet energy scale dependence on pile-up
  - Theoretical uncertainties on signal, top and QCD
  - Statistical uncertainties

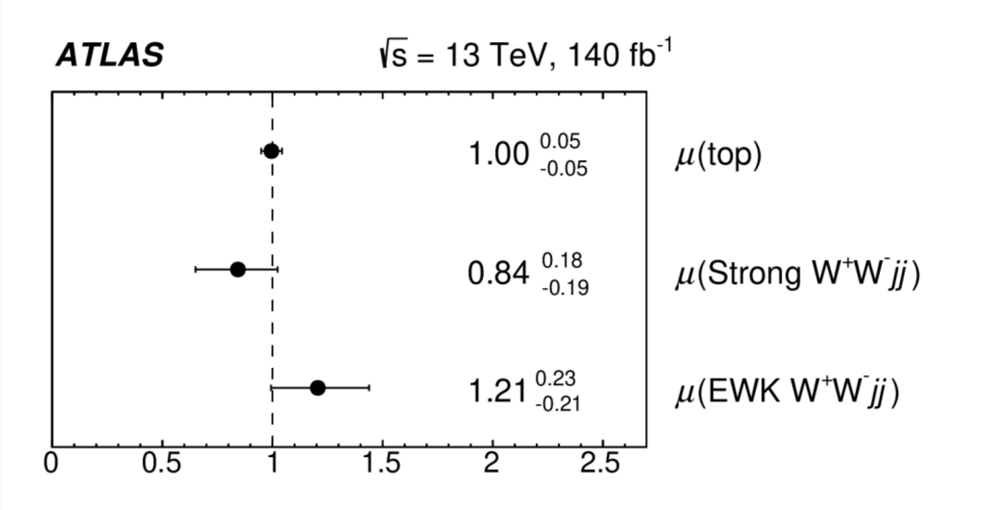


Opposite-sign W^+W^-jj Fiducial Cross Section

- A profile likelihood fit is performed on the NN output simultaneously in the SR and CR
- The fiducial region is defined with selections similar to reconstructed signal region with extra cut on $m_{jj} > 500\ GeV$



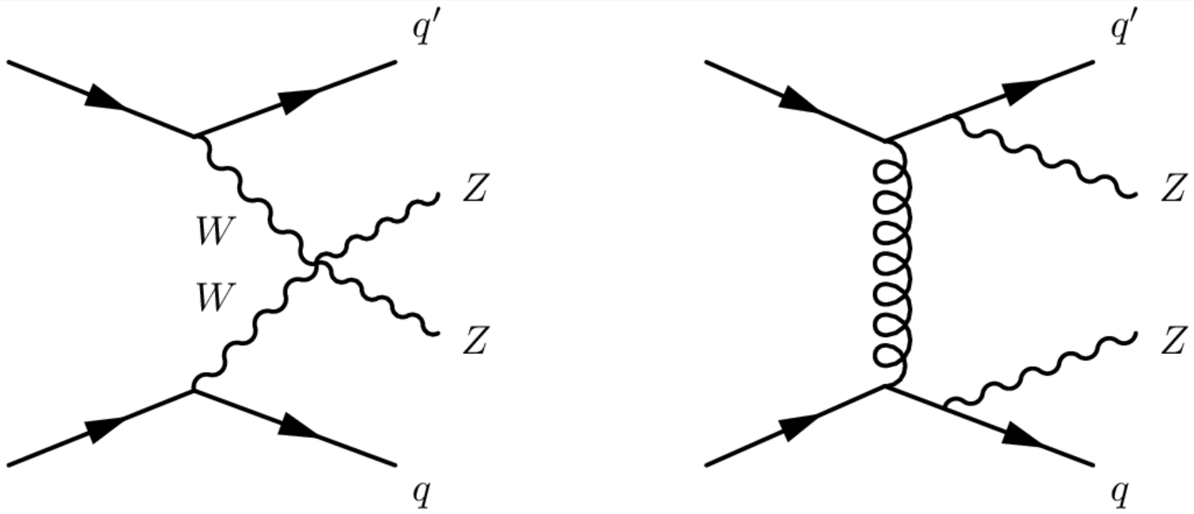




- The NN modelling is in good agreement with data
- The observed (expected) significance is 7.1σ (6.2σ), for both 2 and 3 jets combined.

Differential $ZZjj$

- Sensitive to diverse range of physics Beyond the Standard Model
- EW $ZZjj$ sensitive to WWZ and WWZZ weak-boson self-interactions
- Theoretical prediction of QCD $ZZjj$ sensitive to the accuracy of perturbative QCD calculation (overall production rate and kinematic properties of the final states)



Pure-EW $ZZjj$ Strong $ZZjj$

- Goals:
  - Unfolded differential cross section measurement of interesting kinematic observables
  - Limits on dim-6 and dim-8 EFT operators

Differential $ZZjj$ Strategy

- Selections:
  - Same-flavor opposite-charge (SFOC) lepton pairs ordered by $|m_{ll} - m_Z|$
  - Four lepton system invariant mass $m_{4l} > 130\ GeV$
  - Leading (sub-leading) jets with transverse momentum $> 40\ (30)\ GeV$, dijet invariant mass and separation angle $m_{jj} > 300\ GeV$ & $|\Delta y_{jj}| > 2.0$

$$\zeta = \frac{(y_{4l} - 0.5(y_{j_1} + y_{j_2}))}{\Delta y_{jj}}$$

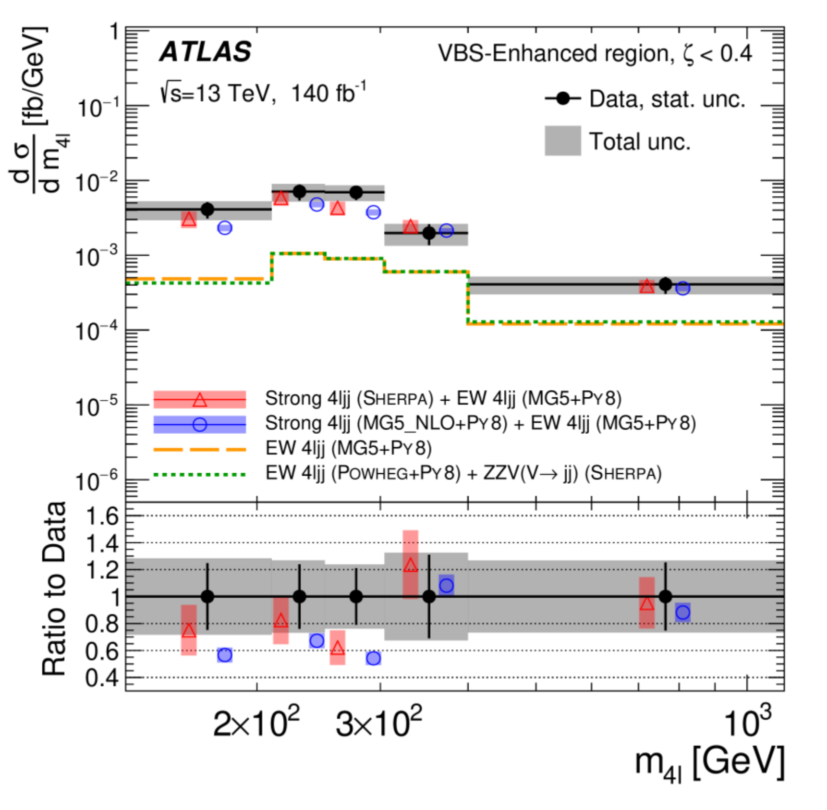
  - Events further categorized into VBS-enhanced ($\zeta < 0.4$) and VBS-suppressed ($\zeta > 0.4$) regions

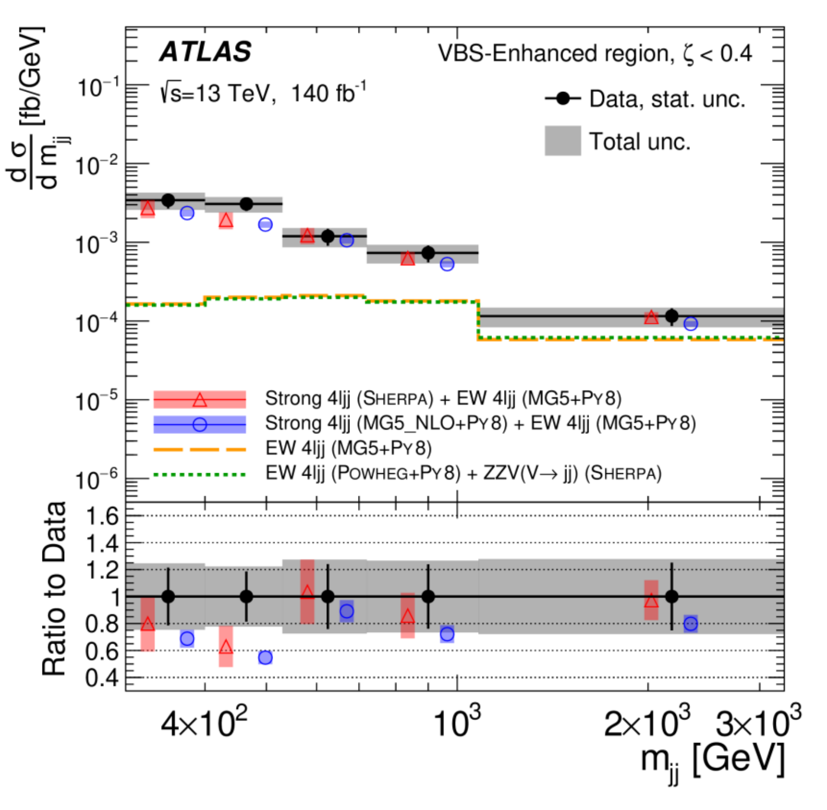
- Inclusive measurements on both EW and strong $ZZjj$ production

- Samples:
  - Nominal strong $ZZjj$: SHERPA
  - Alternative strong $ZZjj$: MG5_NLO+PY8
  - Nominal EW $ZZjj$: MG5+PY8
  - Alternative EW $ZZjj$: POWHEG+PY8

Differential $ZZjj$ Differential Cross Section

- Particle-level measurements in both VBS-enhanced and VBS-suppressed fiducial regions
- Unfolding done with iterative Bayesian method to correct the detector effect



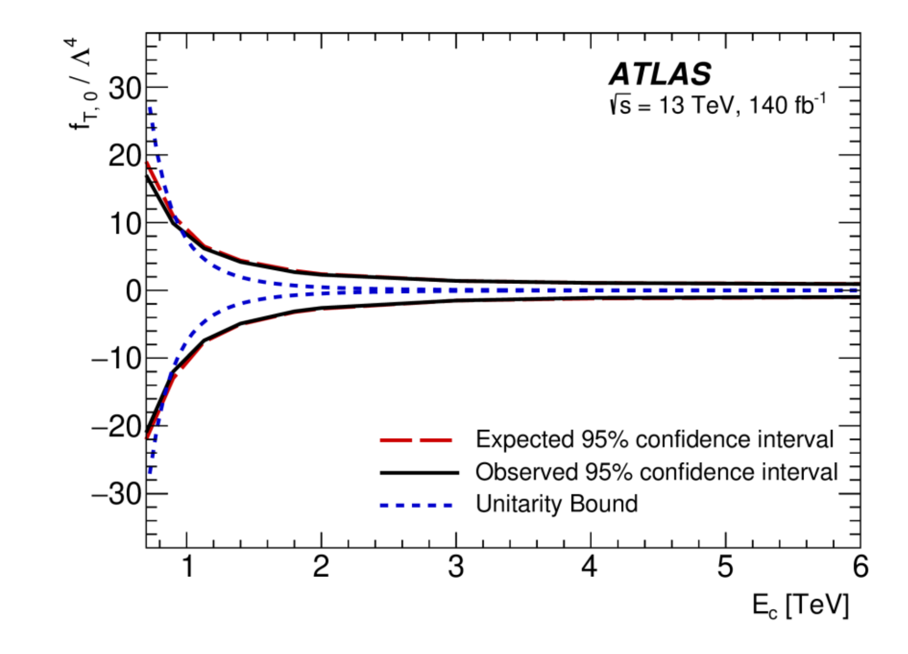


- Generally good agreement between Data and MC prediction
- MG5_NLO+PY8 underestimates the observed data especially in low m_{4l} and m_{jj}

Differential $ZZjj$ EFT Interpretation

- Unfolded distribution for the search of physics beyond the SM
- m_{4l} and m_{jj} are used to set limits on dim-8 and dim-6 EFT operators

Wilson coefficient	$\|\mathcal{M}_{d8}\|^2$ Included	95% confidence interval [TeV^{-4}] Expected	Observed
$f_{T,0}/\Lambda^4$	yes	[-0.98, 0.93]	[-1.00, 0.97]
	no	[-23, 17]	[-19, 19]
$f_{T,1}/\Lambda^4$	yes	[-1.2, 1.2]	[-1.3, 1.3]
	no	[-160, 120]	[-140, 140]
$f_{T,2}/\Lambda^4$	yes	[-2.5, 2.4]	[-2.6, 2.5]
	no	[-74, 56]	[-63, 62]
$f_{T,5}/\Lambda^4$	yes	[-2.5, 2.4]	[-2.6, 2.5]
	no	[-79, 60]	[-68, 67]
$f_{T,6}/\Lambda^4$	yes	[-3.9, 3.9]	[-4.1, 4.1]
	no	[-64, 48]	[-55, 54]
$f_{T,7}/\Lambda^4$	yes	[-8.5, 8.1]	[-8.8, 8.4]
	no	[-260, 200]	[-220, 220]
$f_{T,8}/\Lambda^4$	yes	[-2.1, 2.1]	[-2.2, 2.2]
	no	[-4.6, 3.1]×10^4	[-3.9, 3.8]×10^4
$f_{T,9}/\Lambda^4$	yes	[-4.5, 4.5]	[-4.7, 4.7]
	no	[-7.5, 5.5]×10^4	[-6.4, 6.3]×10^4



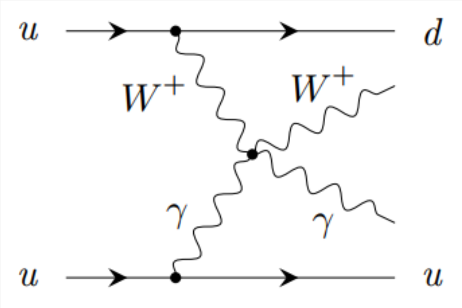
Expected and observed interval of $f_{T,0}$ Wilson coefficient as a function of cut-off scale E_c

- Wilson coefficients are consistent with zero when pure D8 contribution is included

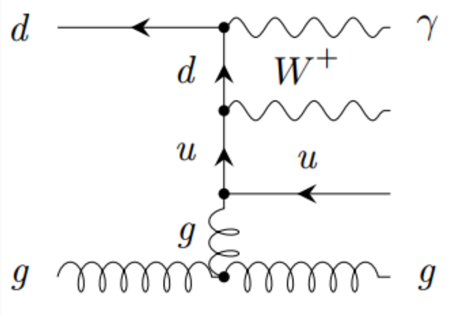
VBS $W\gamma$ jj

- **Analysis targets:**
  - Observation of EWK Wy+jj production
  - Differential cross-section measurements of EWK Wy+jj production
  - Unfold $m_{jj}, p_T^{jj}, \Delta\phi_{jj}, p_T^{lep}, \Delta\phi_{l\gamma}, m_{l\gamma}$
  - EFT Interpretation targeting dimension-8 operators

Signal:

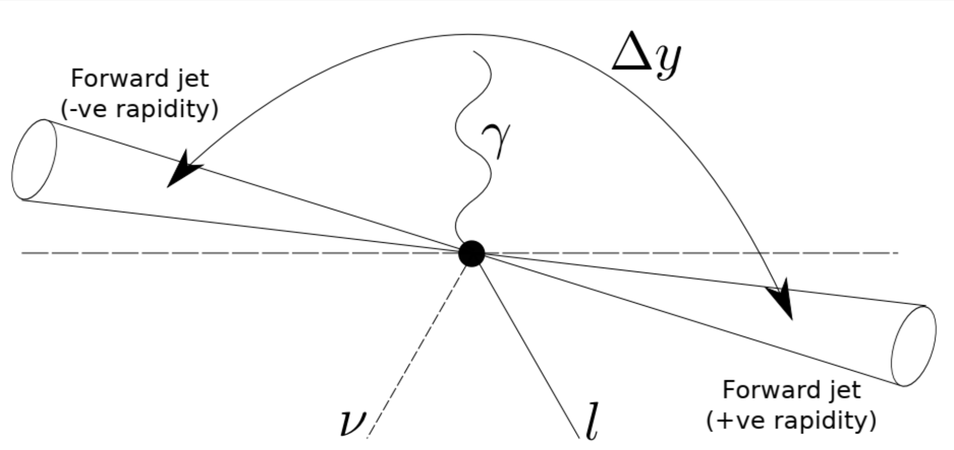


QCD Background:



Typical diagrams

Measurements performed in VBS-enhanced phase-space

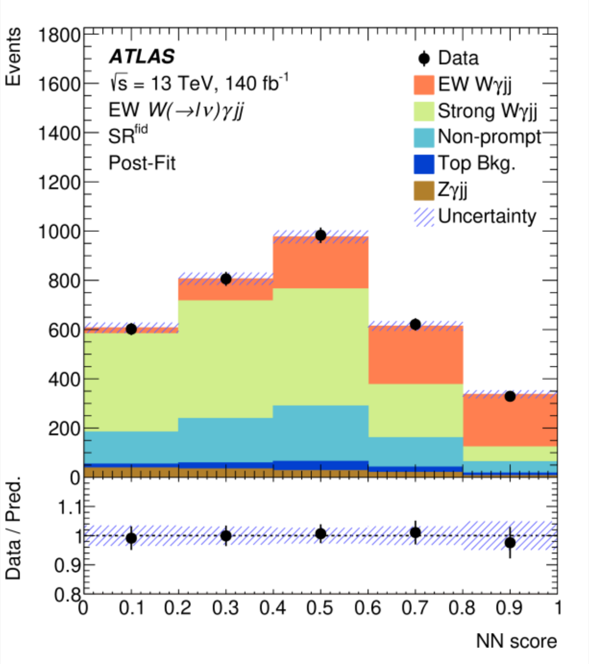


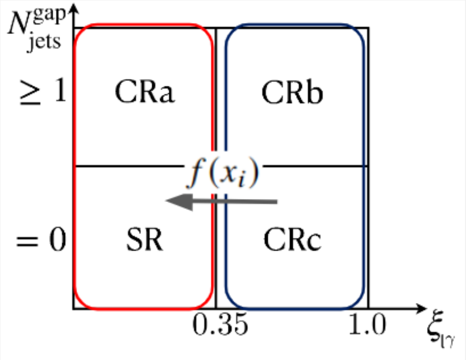
No hadronic activity in central region between two jets, γ and W boson produced in central regions.
Apply high-dijet mass, large forward jet rapidity gap…

VBS $W\gamma$ jj Strategy

TSUNG-DAO LEE INSTITUTE

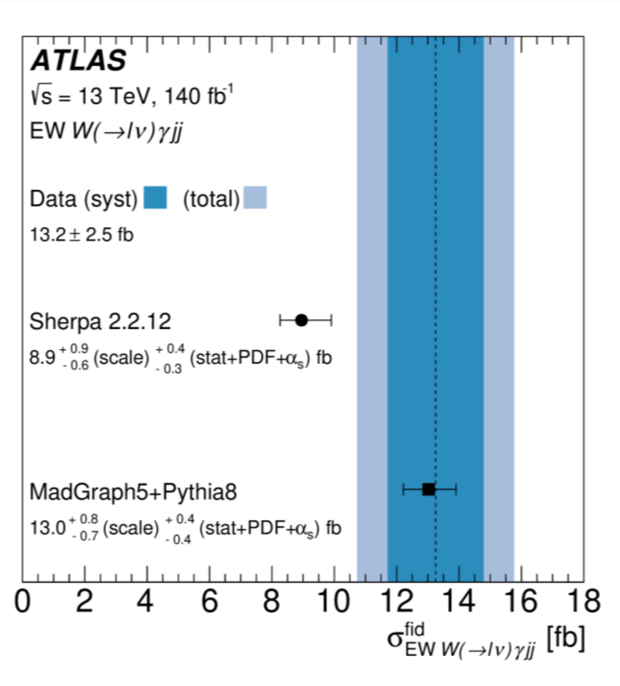
- Selections:
  - Single lepton and missing momentum with $p_T^l > 30\ GeV$ & $E_T^{miss} > 30\ GeV$
  - One photon with $p_T^\gamma > 22\ GeV$ and two jets with $p_T^j > 50\ GeV$
  - VBS signature with large $m_{jj} > 500\ GeV$ and $|\Delta y_{jj}| > 2$
- Data-driven background estimations:
  - Jet faking photons with template fit method
  - Jet faking electron/muons with fake factor method
  - Electron faking photons with tag and probe method
- Observation:
  - NN trained using events after $m_{jj} > 500\ GeV$ & $N_{gapjets} = 0$
  - Profile likelihood fit to the NN score
- Differential measurement:
  - Extract signal + constrain QCD simultaneously
  - Use bootstrapping to evaluate statistical significance of systematic uncertainties
  - Gaussian kernel smoothing for bootstrapped systematics
- EFT interpretation:
  - Iterative Bayesian unfolding to correct detector effects
  - Unfolded distribution for setting limits on dim-8 operators





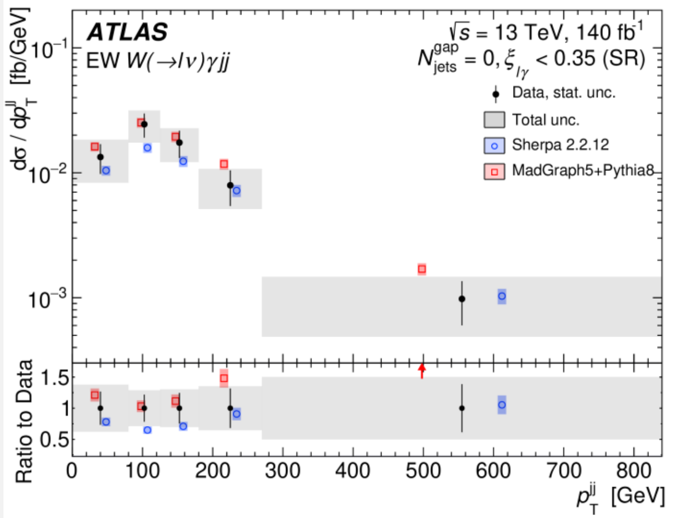
VBS $W\gamma$ jj Measurements

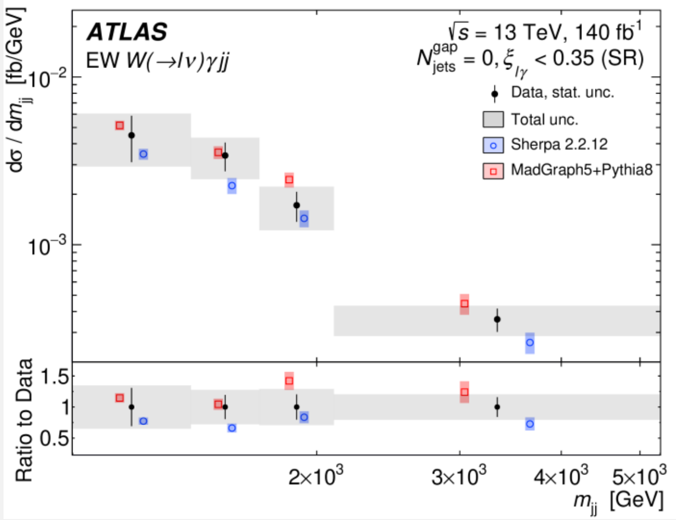
- Fiducial measurements:
  - The observed significance is well above 6 standard deviation compared to the expected significance of 6.3σ
  - Measured signal strength is $\mu_{EW} = 1.5 \pm 0.5$
  - MadGraph5+PYthia8 is in good agreements with data while Sherpa underestimates data within 2 standard deviations



- Differential measurements:
  - Cross sections as a function of $m_{jj}, p_T^{jj}, \Delta\phi_{jj}, p_T^{lep}, \Delta\phi_{l\gamma}, m_{l\gamma}$ are studied
  - Both Sherpa and Madgraph are in good agreement with data within uncertainties
  - MG overshoot at high m_{jj} & p_T^{jj}
  - Sherpa underestimates all six observables

- Analysis is sensitive to 16 dim-8 EFT operators. Aim to set limits on couplings in Warsaw basis.
- Using EFT samples with Eboli model. With full detector simulation





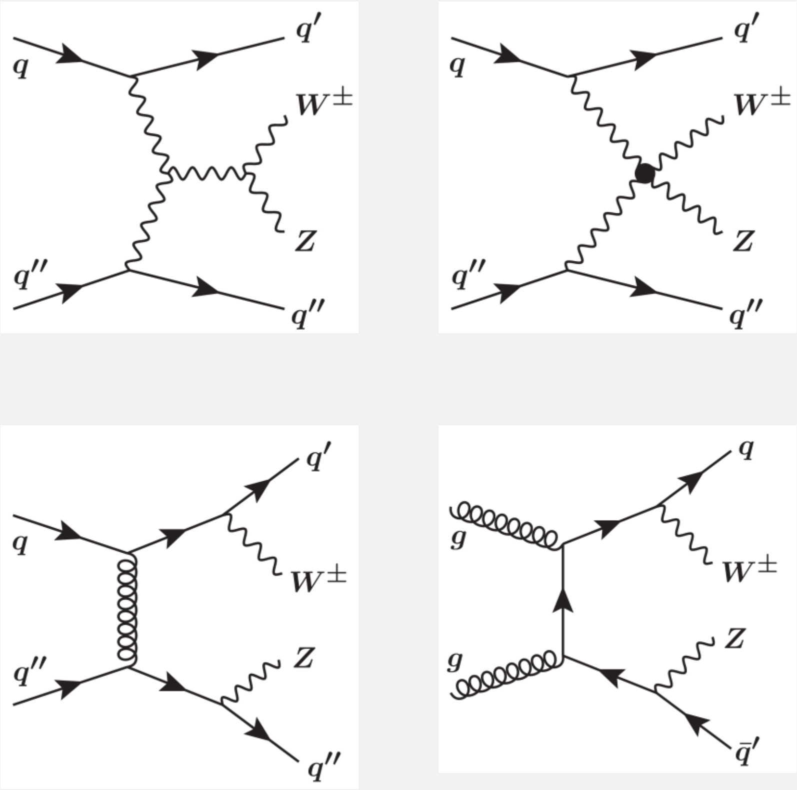
VBS WZ jj

- First observation using 2015-2016 data

- EWK $WZjj$ production:
  - Better precision on fiducial cross section measurement
  - Perform the first EW $WZjj$ differential cross section measurement
  - Simultaneously measure $\sigma_{WZjj-EW}$ and $\sigma_{WZjj-strong}$ in the SR

- Inclusive $WZjj$ production:
  - Better precision on differential cross section measurements
  - Unfold BDT score distribution

- Interpretation of results on EFT frame:
  - Detector level limits using 2D template of $M_T^{WZ} - BDT$ score



VBS WZ jj Strategy

Same BDT score distribution is used in all SRs

- $WZjj - EW$ and $WZjj - Strong$ integrated measurements:
  - Goal: Simultaneous measurement of the integrated $\sigma_{WZjj-EW}$ and $\sigma_{WZjj-Strong}$ cross section in SR
  - Separate the signal region into two categories of different N_{jets}
  - Maximum likelihood fit performed on BDT score distribution

$$
\begin{aligned}
\sigma_{WZjj\text{-EW}} &= \mu_{WZjj\text{-EW}} \cdot \sigma^{\text{th. MC}}_{WZjj\text{-EW}}, \\
\sigma_{WZjj\text{-strong}} &= \mu_{WZjj\text{-QCD}} \cdot \sigma^{\text{th. MC}}_{WZjj\text{-QCD}} + \mu_{WZjj\text{-INT}} \cdot \sigma^{\text{th. MC}}_{WZjj\text{-INT}}, \\
&= \mu_{WZjj\text{-QCD}} \cdot \sigma^{\text{th. MC}}_{WZjj\text{-QCD}} + \sqrt{\mu_{WZjj\text{-EW}}} \cdot \sqrt{\mu_{WZjj\text{-QCD}}} \cdot \sigma^{\text{th. MC}}_{WZjj\text{-INT}}
\end{aligned}
$$

- $WZjj - EW$ and $WZjj - Strong$ differential measurements:
  - SR separated into bins of N_{jets} and m_{jj}
  - Simultaneous fit to the data of the BDT score distribution of events in each bin is performed

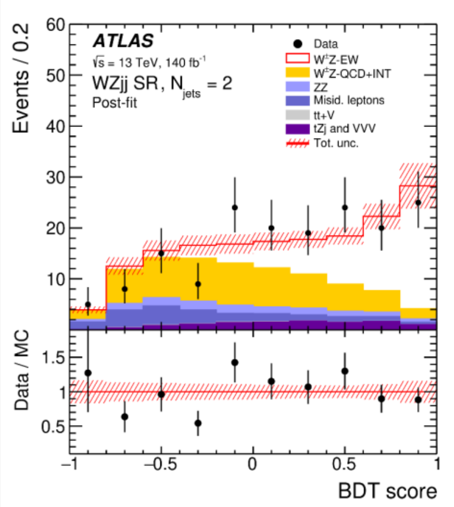
$$
\sigma^{i}_{WZjj\text{-EW}} = \mu^{i}_{WZjj\text{-EW}} \cdot \sigma^{i,\text{ th. MC}}_{WZjj\text{-EW}} = \frac{N^{i}_{\text{fit}}}{\mathcal{L} \cdot C_i}, \quad C_i = \frac{N^{i}_{\text{MC, det.}}}{N^{i}_{\text{MC, part.}}}
$$

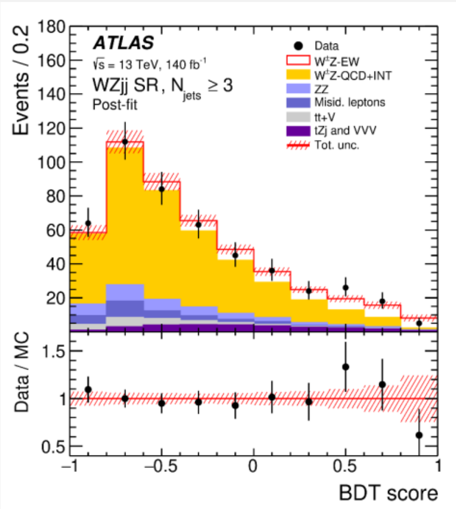
- Differential $WZjj$ measurements:
  - Iterative Bayesian method with 3 iterations used to correct detector effects
  - MC scaled to data to better model the data and minimize unfolding uncertainty
  - Variables: $M_T^{WZ}, \Delta\phi(W,Z), N_{jets}, m_{jj}, \Delta y_{jj}, \Delta\phi_{jj}, N_{jets(gap)}, Z_{j3}, BDT\ score$

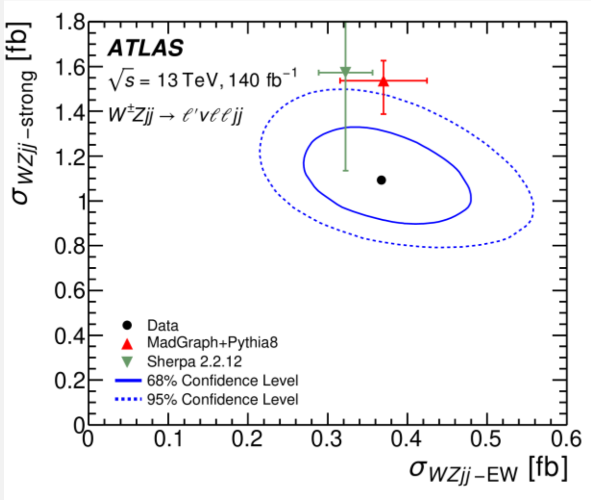
VBS WZ jj Results

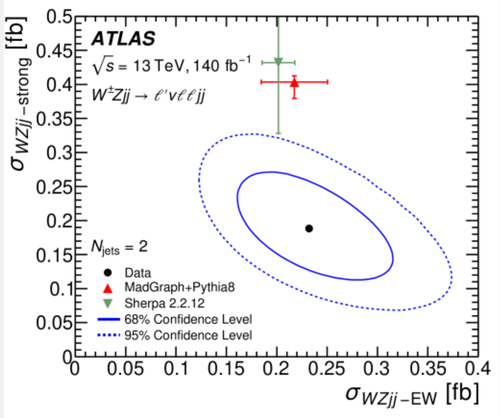
- $WZjj - EW$ and $WZjj - Strong$ integrated measurements:

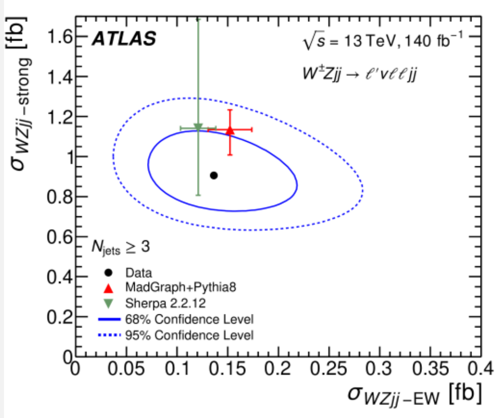
$$
\begin{aligned}
\sigma_{WZjj\text{-EW}} &= 0.368 \pm 0.037\,(\text{stat.}) \pm 0.059\,(\text{syst.}) \pm 0.003\,(\text{lumi.})\ \text{fb} \\
&= 0.37 \pm 0.07\ \text{fb}, \\
\sigma_{WZjj\text{-strong}} &= 1.093 \pm 0.066\,(\text{stat.}) \pm 0.131\,(\text{syst.}) \pm 0.009\,(\text{lumi.})\ \text{fb} \\
&= 1.09 \pm 0.14\ \text{fb},
\end{aligned}
$$





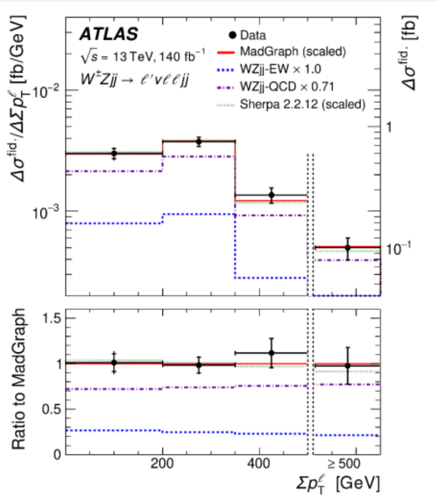


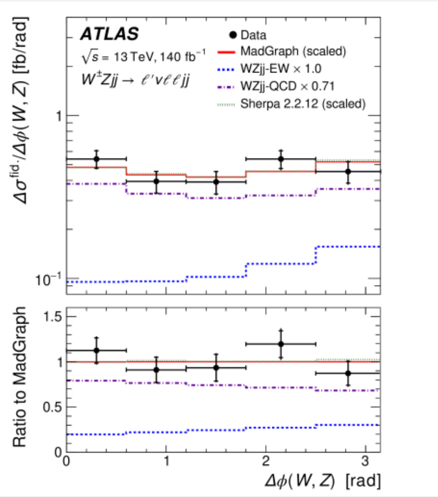


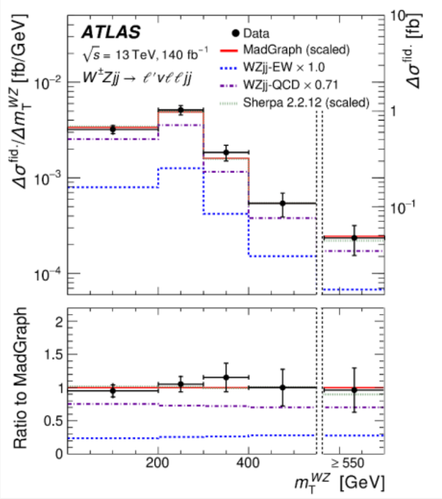


- $WZjj - EW$ and $WZjj - Strong$ differential measurements:

- Differential $WZjj$ measurements:

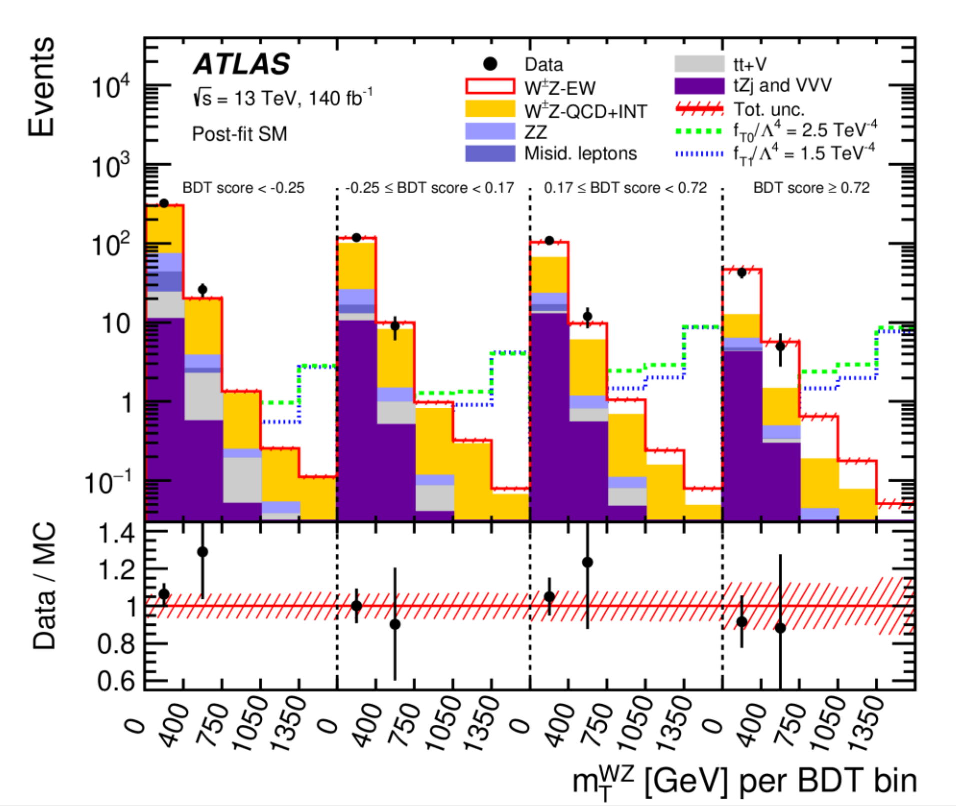






VBS WZ jj Results EFT

- No deviation with respect to the SM predictions is observed
- Two dimensional distribution $M_T^{WZ} - BDT$ used for extraction of limits



	Expected $[\text{TeV}^{-4}]$	Observed $[\text{TeV}^{-4}]$
f_{T0}/Λ^4	[-0.80, 0.80]	[-0.57, 0.56]
f_{T1}/Λ^4	[-0.52, 0.49]	[-0.39, 0.35]
f_{T2}/Λ^4	[-1.6, 1.4]	[-1.2, 1.0]
f_{M0}/Λ^4	[-8.3, 8.3]	[-5.8, 5.6]
f_{M1}/Λ^4	[-12.3, 12.2]	[-8.6, 8.5]
f_{M7}/Λ^4	[-16.2, 16.2]	[-11.3, 11.3]
f_{S02}/Λ^4	[-14.2, 14.2]	[-10.4, 10.4]
f_{S1}/Λ^4	[-42, 41]	[-30, 30]

Expected and observed lower and upper 95% CL limits on the Wilson coefficients

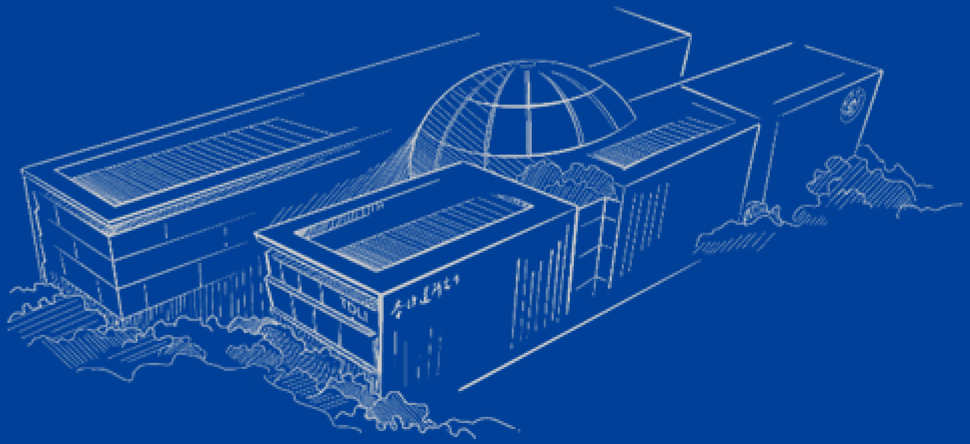
Binning optimization:
BDT: [-1.0, -0.25, 0.17, 0.72, 1.0]
M_T^{WZ}: [0, 400, 750, 1050, 1350, ∞]

Coefficients associated to T0 and T1 are the most tightly constraint

Summary

- Several measurements are reported about EW or inclusive production of different final states
- Generally the observed data has good agreements with predictions
- Limits on EFT operators are set in most cases
- Results are bringing challenge to electroweak cross section calculations and kinematic modellings

谢 谢！



Backup

Same-sign $W^{\pm}W^{\pm}jj$ Samples

Process, short description	ME Generator + parton shower	Order	Tune	PDF set in ME
EW, Int, QCD $W^{\pm}W^{\pm}jj$, nominal signal	MadGraph5_aMC@NLO2.6.7 + Herwig7.2	LO	default	NNPDF3.0nlo
EW, Int, QCD $W^{\pm}W^{\pm}jj$, alternative shower	MadGraph5_aMC@NLO2.6.7 + Pythia8.244	LO	A14	NNPDF3.0nlo
EW $W^{\pm}W^{\pm}jj$, NLO QCD approx.	Sherpa2.2.11	+0,1j@LO	Sherpa	NNPDF3.0nnlo
EW $W^{\pm}W^{\pm}jj$, NLO QCD approx.	Powheg Boxv2 + Pythia8.230	NLO (VBS approx.)	AZNLO	NNPDF3.0nlo
QCD $W^{\pm}W^{\pm}jj$, NLO QCD approx.	Sherpa2.2.2	+0,1j@LO	Sherpa	NNPDF3.0nnlo
VV (leptonic)	Sherpa2.2.2	+0,1j@NLO; +2,3j@LO	Sherpa	NNPDF3.0nnlo
VVV	Sherpa2.2.1 (leptonic) & Sherpa2.2.2 (one $V \to jj$)	+0,1j@LO	Sherpa	NNPDF3.0nnlo
W/Z + jets	MadGraph5_aMC@NLO2.3.2.p1 + Pythia8.210	+0,1,2,3,4j@LO	A14	NNPDF3.0nlo
$t\bar{t}$ Single t (s- and Wt-channel)	Powheg Boxv2 + Pythia8	NLO	A14	NNPDF3.0nlo
Single t (t-channel)	Powheg Boxv2 + Pythia8	NLO	A14	NNPDF3.0nlo4f
$t\bar{t}V$	MadGraph5_aMC@NLO2.3.3.p0 + Pythia8.210	NLO	A14	NNPDF3.0nlo
$V\gamma$	Sherpa2.2.11	MEPS@NLO	A14	NNPDF3.0nnlo

Same-sign $W^{\pm}W^{\pm}jj$ Post-fit Yields

李政道研究所
TSUNG-DAO LEE INSTITUTE

Process	ee	$e\mu$	μe	$\mu\mu$	Combined
$W^{\pm}W^{\pm}jj$ EW	32.9 ± 3.4	81 ± 8	73 ± 7	90 ± 9	277 ± 26
$W^{\pm}W^{\pm}jj$ QCD	1.7 ± 0.5	8.0 ± 2.4	7.1 ± 2.1	9.7 ± 2.9	27 ± 8
$W^{\pm}W^{\pm}jj$ Int	1.00 ± 0.22	2.4 ± 0.5	2.1 ± 0.4	2.7 ± 0.6	8.2 ± 1.7
$W^{\pm}Zjj$ QCD	5.5 ± 0.7	18.2 ± 2.1	18.2 ± 2.2	14.0 ± 1.7	56 ± 6
$W^{\pm}Zjj$ EW	1.69 ± 0.14	4.9 ± 0.4	4.1 ± 0.4	4.2 ± 0.4	14.9 ± 1.2
Non-prompt	8.4 ± 1.6	14.9 ± 2.4	10.2 ± 1.6	21 ± 5	55 ± 9
$V\gamma$	1.5 ± 0.7	6.1 ± 2.4	5.5 ± 2.8	—	13 ± 5
Charge misid.	4.3 ± 2.0	5.4 ± 1.2	1.4 ± 0.4	—	11 ± 4
Other prompt	0.99 ± 0.25	2.5 ± 0.5	1.9 ± 0.5	1.4 ± 1.4	6.8 ± 2.1
Total	58 ± 4	143 ± 7	123 ± 6	143 ± 8	468 ± 21
Data	52	149	127	147	475

Opposite-sign W^+W^-jj Selections

Category	Requirements
Leptons	$p_T > 27$ GeV $\|\eta\| < 2.47$ excluding $1.37 < \|\eta\| < 1.52$ (electrons) $\|\eta\| < 2.5$ (muons) Identification: `Tight` Isolation: `Gradient` (electrons), `Tight_FixedRad` (muons) $\|d_0/\sigma_{d_0}\| < 5$ (electrons), $\|d_0/\sigma_{d_0}\| < 3$ (muons) $\|z_0 \sin\theta\| < 0.5$ mm
b-jets	$p_T > 20$ GeV and $\|\eta\| < 2.5$ (`DL1r` b-tagging with 85% efficiency)
Jets	$p_T > 25$ GeV and $\|\eta\| < 4.5$
Events	One electron and one muon with opposite electric charges No additional lepton with $p_T > 10$ GeV, `Loose` isolation, `Tight`/`Medium` (electrons) and `Loose` (muons) identification $m_{e\mu} > 80$ GeV $E_T^{miss} > 15$ GeV No b-jet Two or three jets $\zeta > 0.5$

Selection cuts on physics objects that define the signal region

VBS $W\gamma$ jj EFT

李政道研究所 TSUNG-DAO LEE INSTITUTE

• EFT Interpretation

- Analysis is sensitive to 16 dim-8 EFT operators. Aim to set limits on couplings in Warsaw basis.
- 8 tensor-like operators containing field strength tensors: T0,T1,T2,T3,T4,T5,T6,T7
- 7 "mixed scaler" operators containing field strength tensor and M0,M1,M2,M3,M4,M5,M7 covariant Higgs derivatives.
- Using EFT samples with Eboli model. With full detector simulation
- Sample decomposed between SM + interference + EFT

c	Expected 95% CL Limit (Asymptotic)	Expected 95% CL Limit (Toys)	Observed 95% CL Limit
f_{T0}	[-3.86,4.09]	[-4.32,4.32]	[-3.29,3.5]
f_{T1}	[-2.35,2.67]	[-2.67,2.67]	[-1.99,2.27]
f_{T2}	[-5.66,6.67]	[-6.68,6.68]	[-4.76,5.69]
f_{T3}	[-4.9,5.63]	[-5.8,5.8]	[-4.14,4.79]
f_{T4}	[-4.14,4.34]	[-4.64,4.64]	[-3.5,3.69]
f_{T5}	[-2.73,2.8]	[-3.25,3.25]	[-2.34,2.4]
f_{T6}	[-1.99,2.08]	[-2.22,2.22]	[-1.69,1.77]
f_{T7}	[-5.08,5.4]	[-5.74,5.74]	[-4.3,4.59]
f_{M0}	[-46.22,44.2]	[-51.47,51.47]	[-39.29,37.55]
f_{M1}	[-68.14,71.61]	[-60.69,60.69]	[-58.23,61.0]
f_{M2}	[-16.46,16.17]	[-17.93,17.93]	[-13.99,13.81]
f_{M3}	[-24.57,25.43]	[-26.55,26.55]	[-20.85,21.56]
f_{M4}	[-27.95,27.76]	[-30.02,30.02]	[-23.85,23.85]
f_{M5}	[-22.42,27.68]	[-26.16,26.16]	[-19.09,23.33]
f_{M7}	[-124.07,120.06]	[-145.48,145.48]	[-105.42,102.04]

Table 57: Expected limits on dimension-8 operators modifying the $WW\gamma\gamma$ coupling when fitting $M_{l\gamma}$. Work in progress

Fit all 6 extracted distributions for expected limits
Madgraph is used for EFT samples production. Limits set using unfolded distribution