Multiboson and VBS measurements at CMS and ATLAS Experiments

Trisha Debnath, *LLR- École Polytechnique*

on behalf of the CMS and ATLAS Collaborations

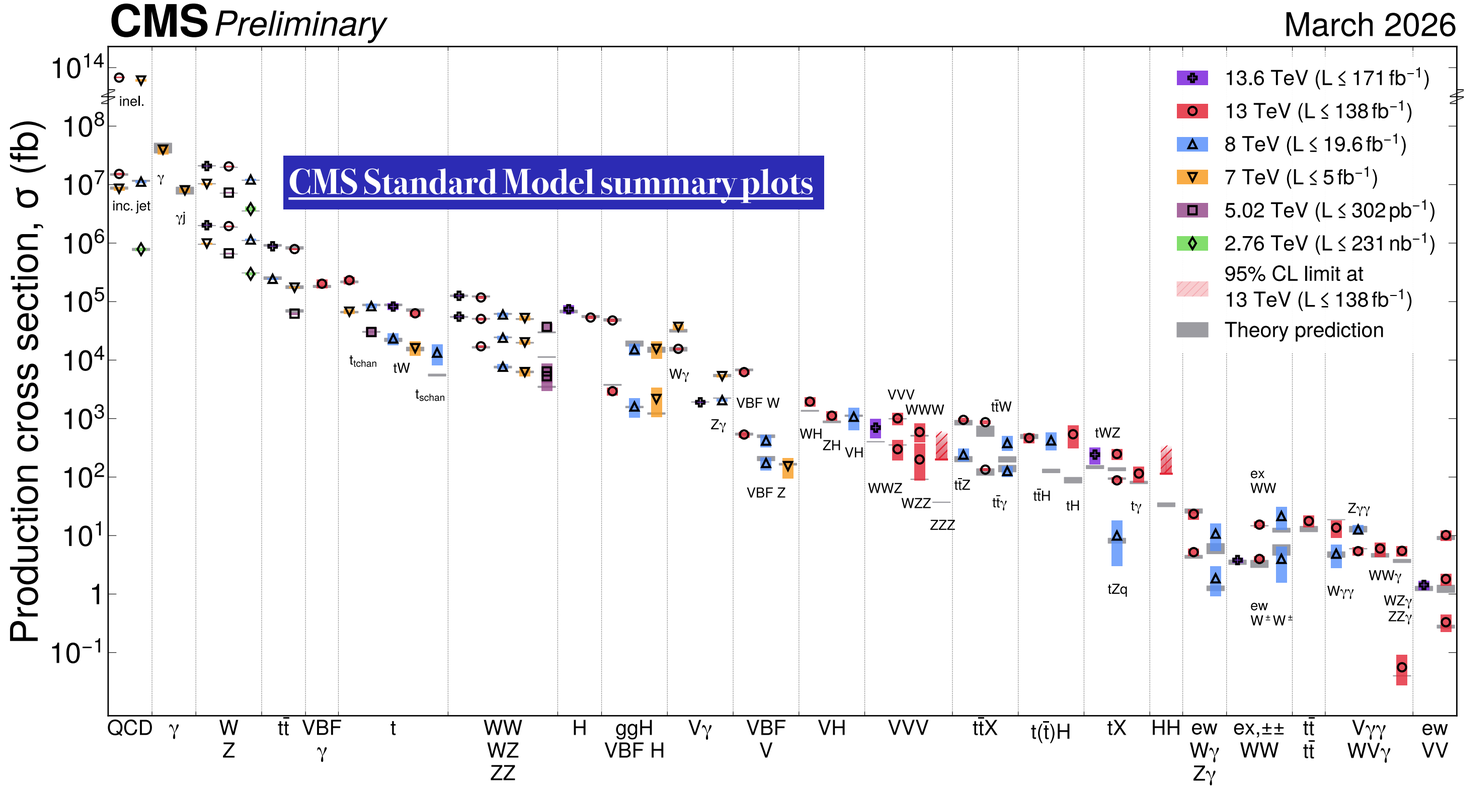
SM@LHC Conference, Turin 7-10 April 2026

Why multibosons and VBS?

-All that remains is more and more precise measurement (Lord Kelvin)

Gauge bosons self-interact due to the **non-Abelian** structure of the electroweak (EW) theory.

- **Diboson measurements** allow us to **validate EW gauge sector** and **provide precision tests** for **triple gauge coupling** processes.
- **Triboson processes** explore rare interactions, provide **sensitivity to new physics** and directly probe **quartic gauge couplings.**
- **Vector boson scattering** directly probes **quartic gauge couplings** and **electroweak symmetry breaking**.



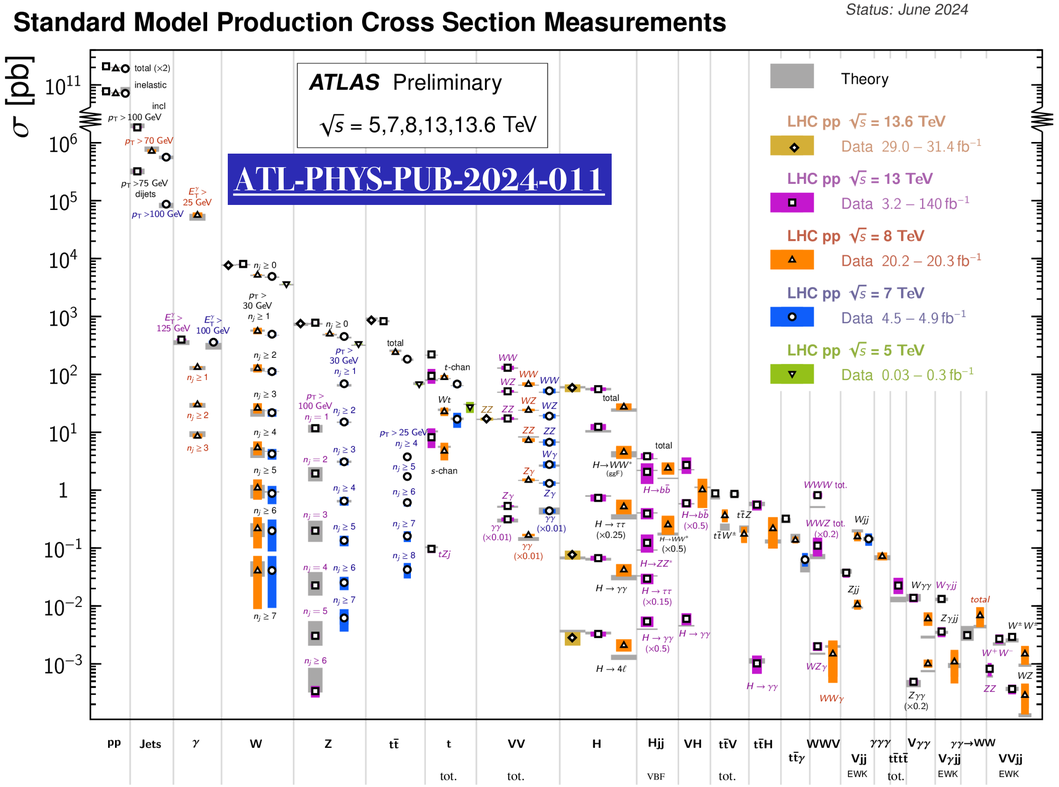
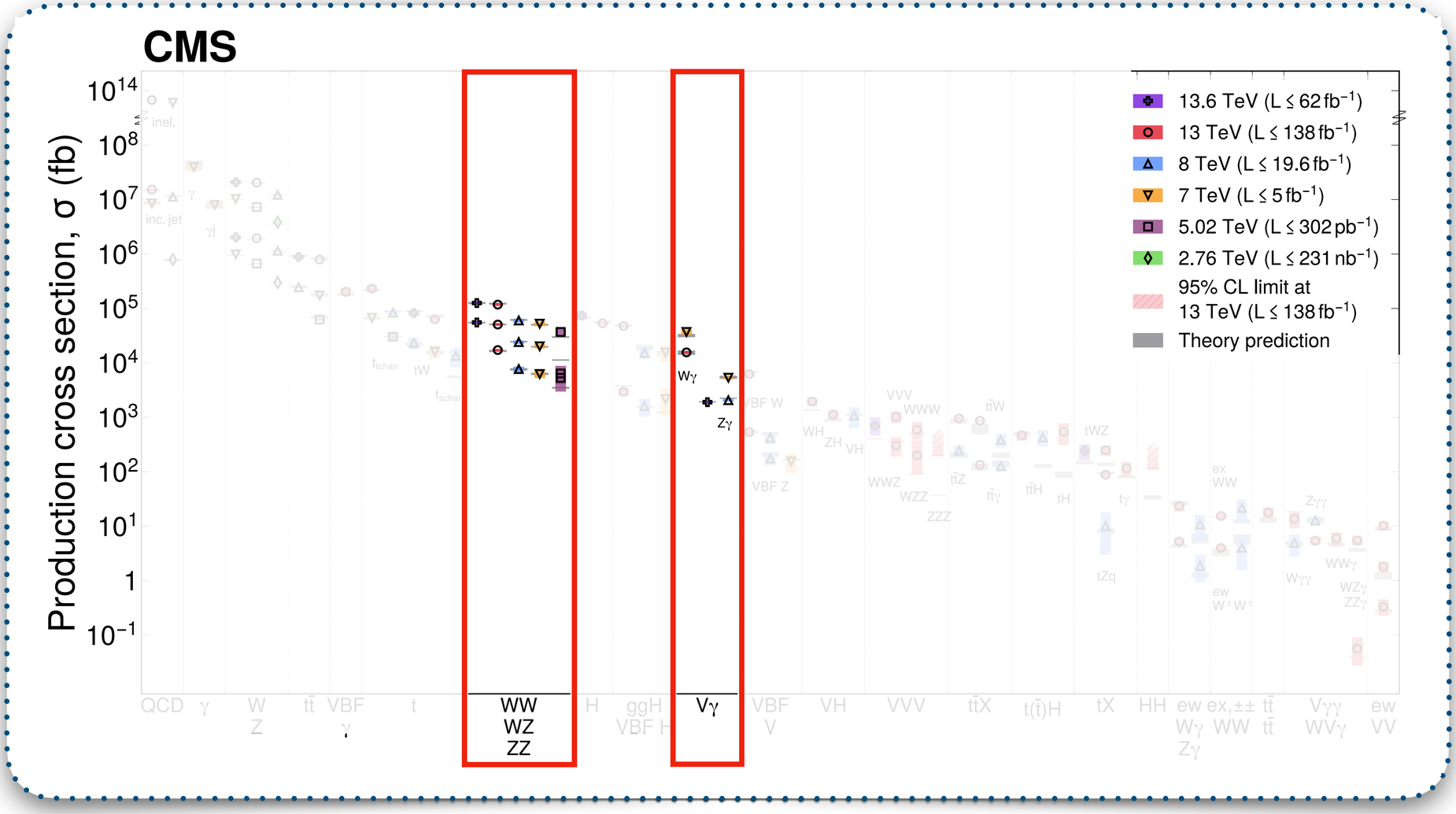


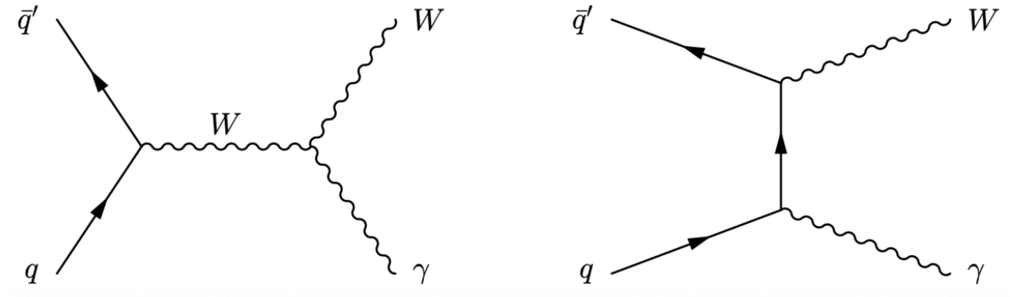
Figure: Summary of the cross-section measurements of Standard Model processes from CMS (left) and ATLAS (right) experiments.

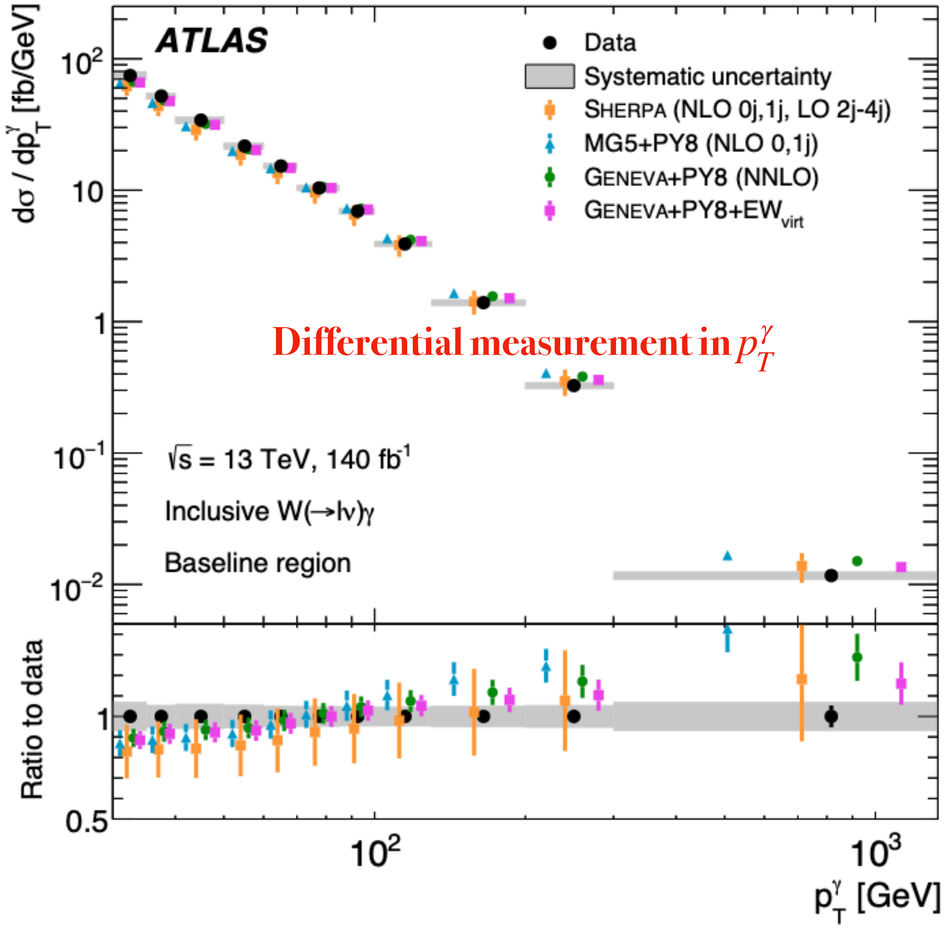
Diboson measurements: $W\gamma$, $Z\gamma$, WW, WZ, ZZ

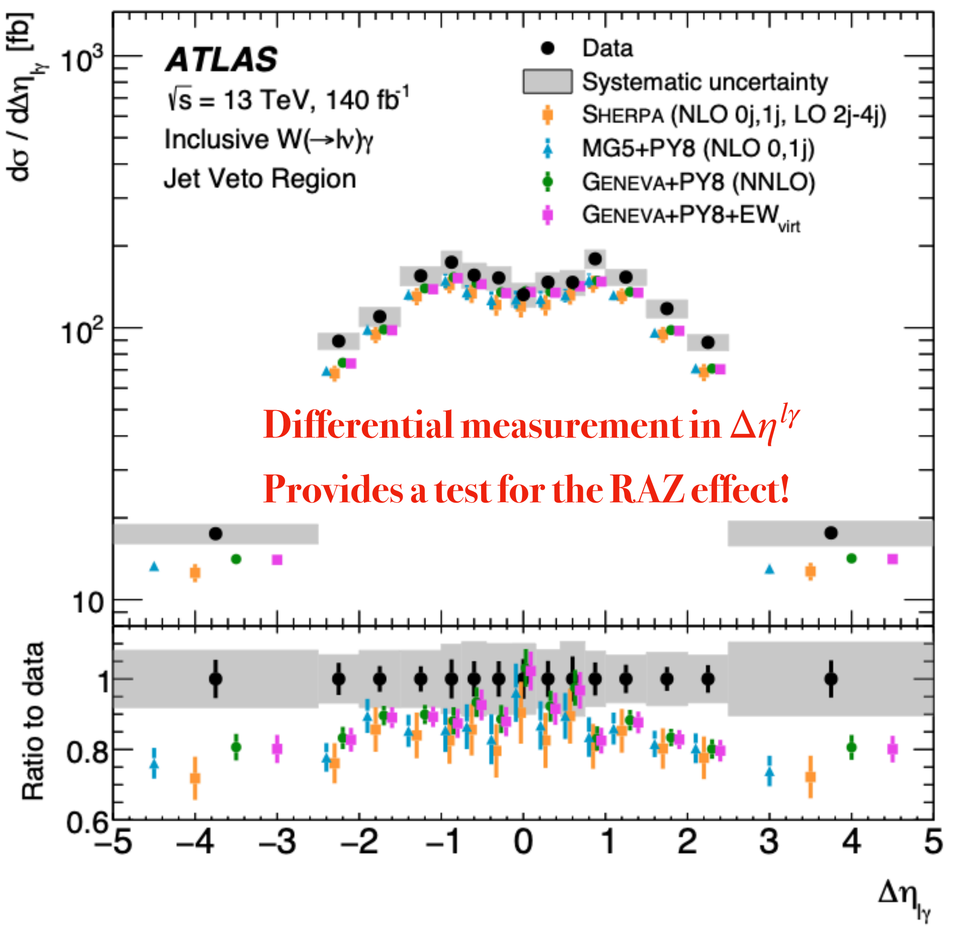


$W\gamma$ measurements (Run 2)

- Latest differential cross section measurement from ATLAS with full Run 2 data, using the observables: $p_T^{\gamma}, p_T^{l}, \eta^{\gamma}, m_{l\gamma}, m_T^{l\nu\gamma}$







Submitted to EPJC
arxiv:2603.22478

CMS Run 2 Result: PRD 105 (2022) 052003

$W\gamma$ measurements (Run 2)

$$\mathscr{L}_{EFT} = \mathscr{L}_{SM} + \sum_i \frac{\bar{C}_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_i \frac{\bar{C}_i^{(8)}}{\Lambda^4}\mathcal{O}_i^{(8)} + \dots$$

- CP sensitive: DNN based variable CP-odd observable:

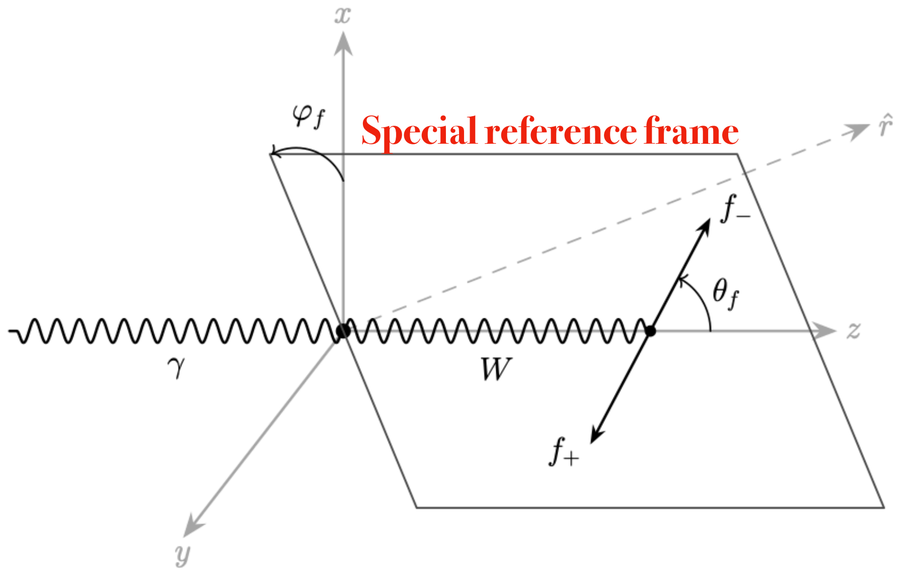
  $O_{NN} = P_+ - P_-$, where $P_+(P_-)$ is the probability of positive (negative) weighted interference event.

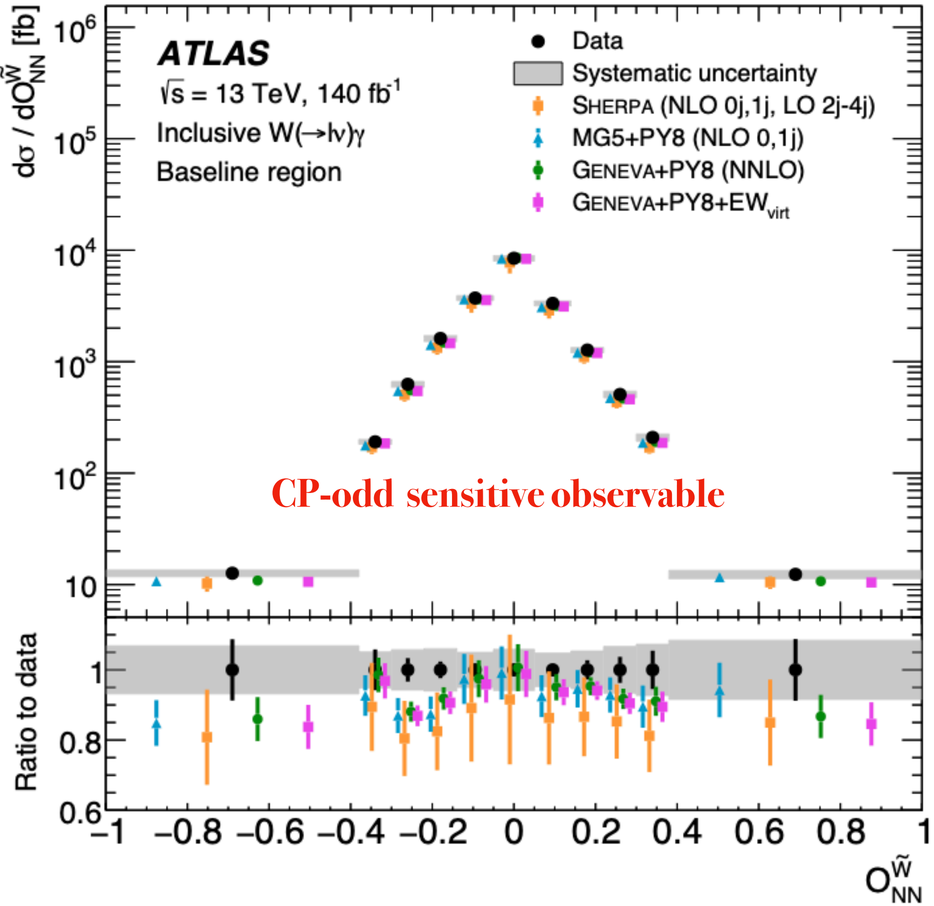
Cross-section in presence of $\mathcal{O}$ operator: $\sigma = \sigma_{SM} + C\sigma_{int} + C^2\sigma_{BSM}$

Exploit the energy growth of BSM —> Measure high energy p_T^γ

Issue :

At LO, SM(6) interference is not observable in inclusive quantities.





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$W\gamma$ measurements (Run 2)

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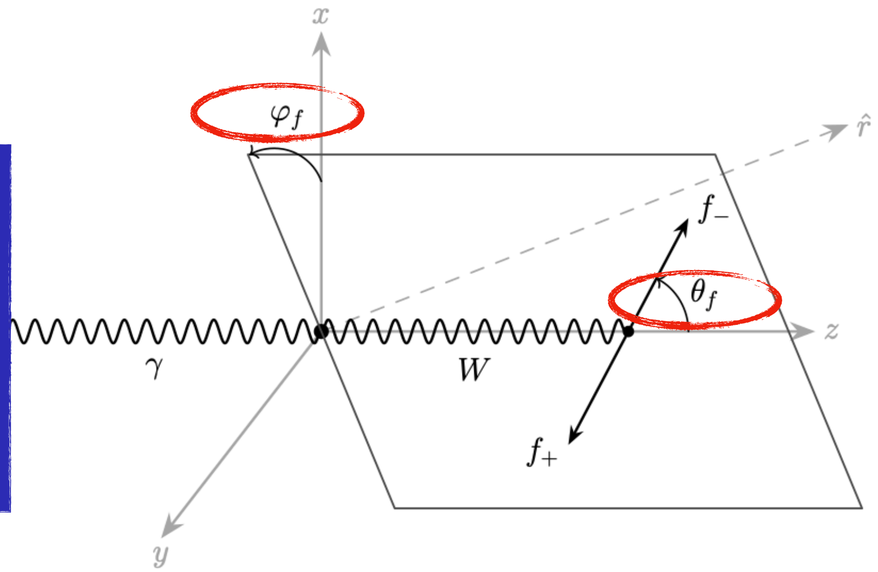
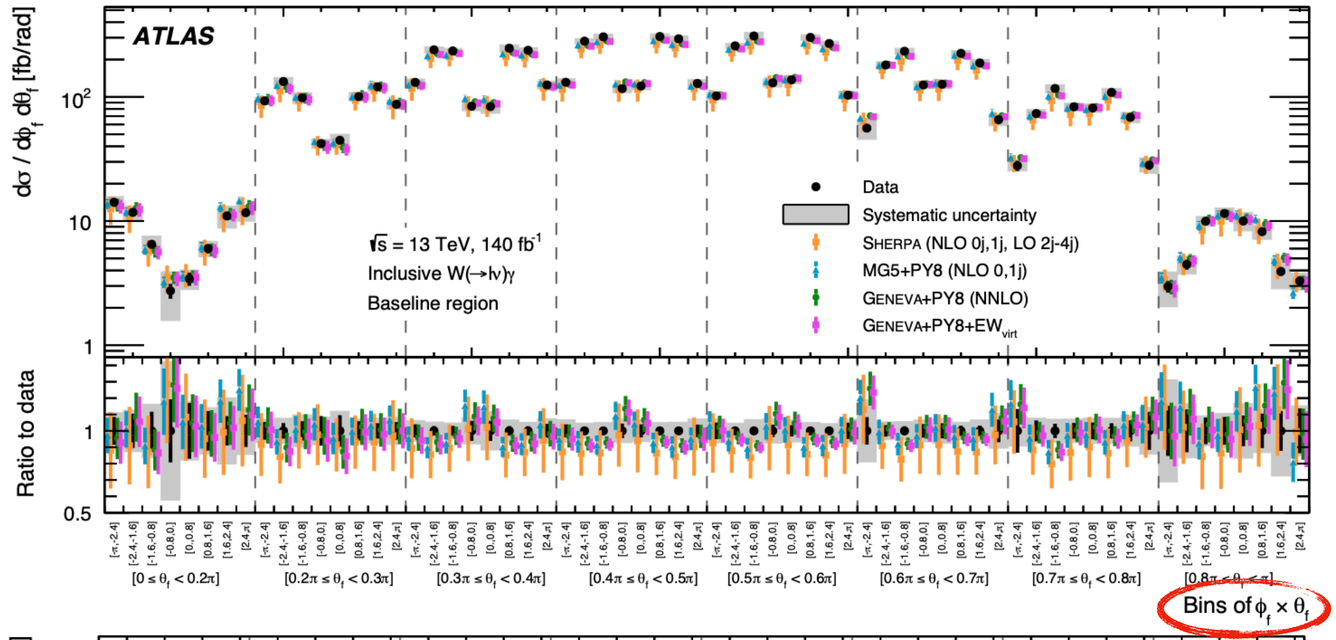
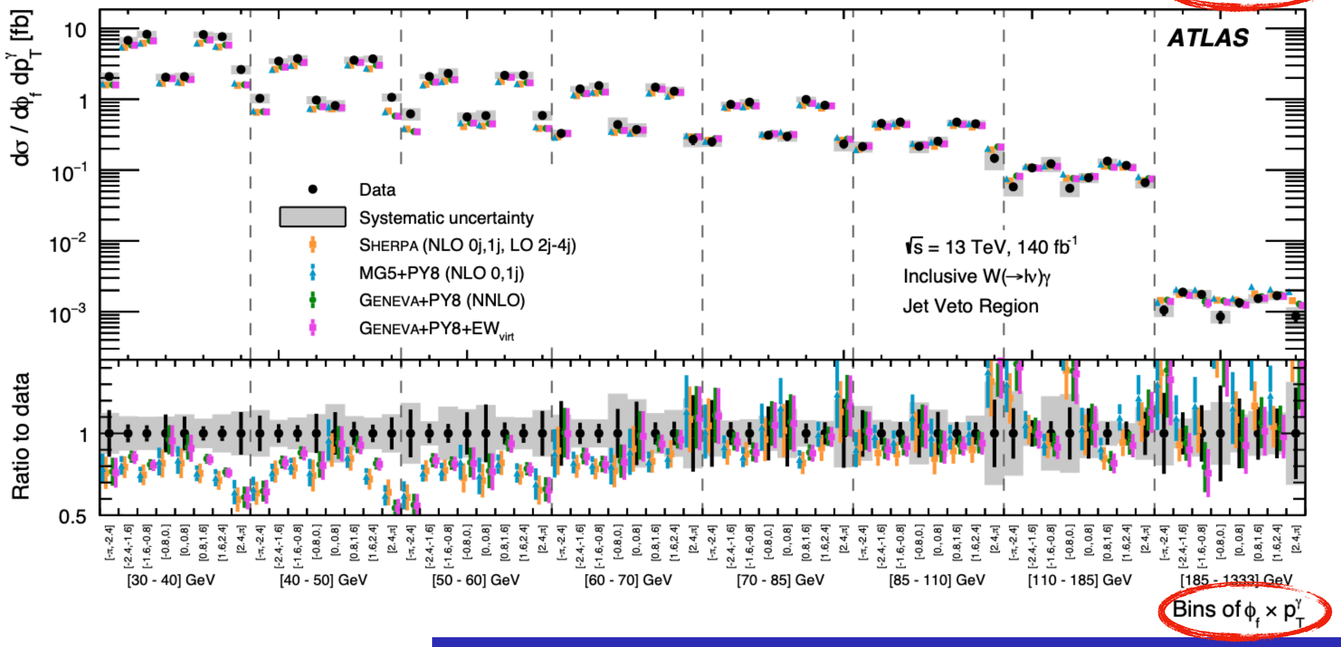


- $\theta_f \times \phi_f$ probes the W boson spin density matrix.

- $p_T^\gamma \times \phi_f$ to restore sensitivity to EFT interference effects that grow with energy.





$W\gamma$ measurements (Run 2)

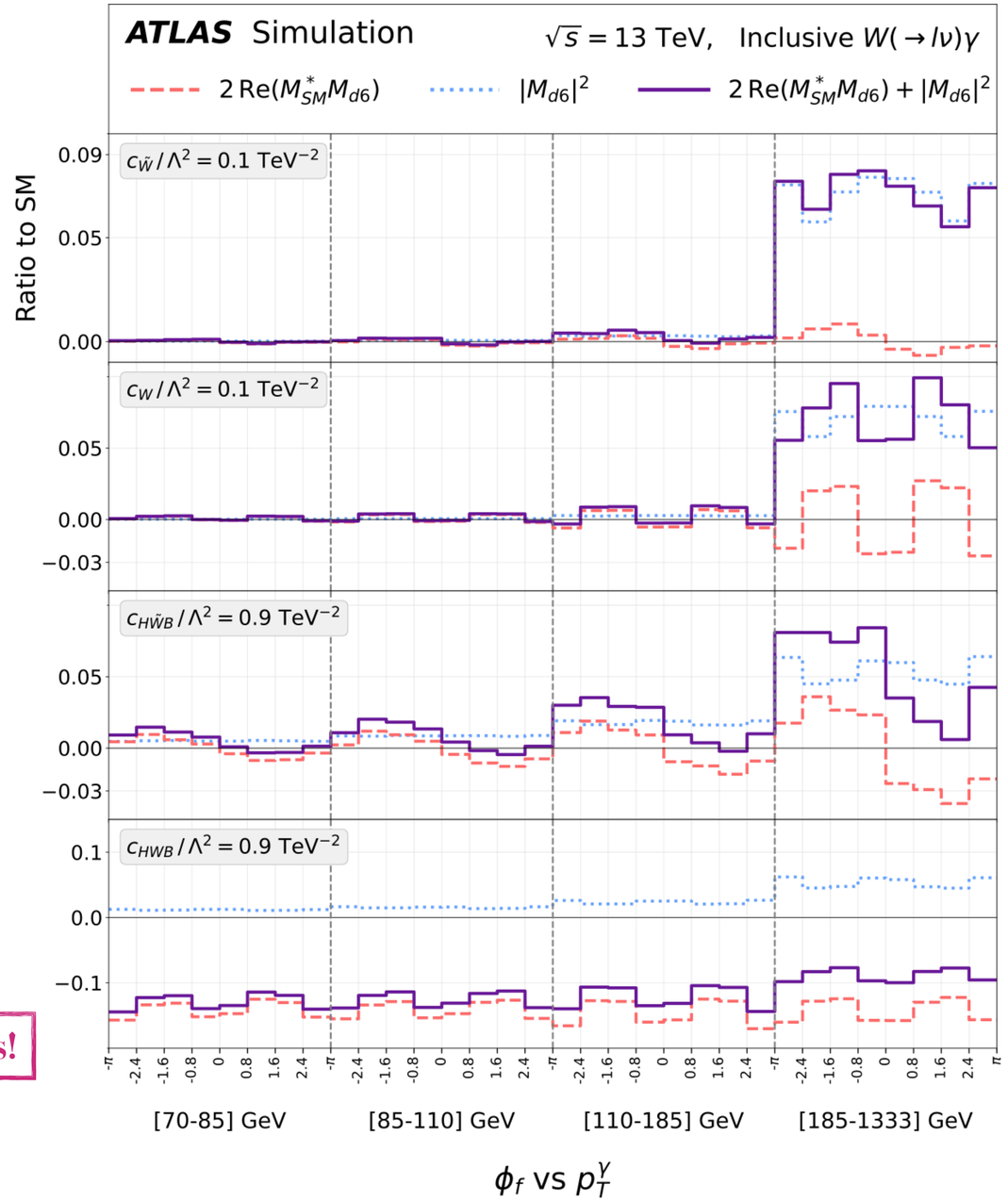
Sensitive to four operators
- c_W, c_{HWB} : CP-even
- $c_{\tilde{W}}, c_{H\tilde{W}B}$: CP-odd

Wilson coefficient	Observable	Includes $\lvert\mathcal{M}_{d6}\rvert^2$	k-factor	95% CL [TeV^{-2}] Expected	Observed
c_W/Λ^2	$\phi_f \times p_{\mathrm{T}}^{\gamma}$	no	no	$[-0.37, 0.38]$	$[-0.42, 0.36]$
		yes	no	$[-0.12, 0.11]$	$[-0.06, 0.06]$
		no	yes	$[-0.23, 0.25]$	$[-0.28, 0.21]$
		yes	yes	$[-0.09, 0.09]$	$[-0.05, 0.05]$
$c_{\tilde{W}}/\Lambda^2$	$O_{\mathrm{NN}}^{\tilde{W}}$	no	no	$[-0.53, 0.54]$	$[-0.74, 0.23]$
		yes	no	$[-0.61, 0.36]$	$[-0.67, 0.19]$
		no	yes	$[-0.32, 0.32]$	$[-0.45, 0.14]$
		yes	yes	$[-0.43, 0.25]$	$[-0.54, 0.11]$
c_{HWB}/Λ^2	$\phi_f \times p_{\mathrm{T}}^{\gamma}$	no	no	$[-1.21, 0.90]$	$[-0.67, 1.21]$
		yes	no	$[-0.97, 0.82]$	$[-0.47, 0.67]$
		no	yes	$[-0.84, 0.62]$	$[-1.09, 0.50]$
		yes	yes	$[-0.76, 0.60]$	$[-0.58, 0.38]$
$c_{H\tilde{W}B}/\Lambda^2$	$O_{\mathrm{NN}}^{H\tilde{W}B}$	no	no	$[-0.39, 0.39]$	$[-0.59, 0.13]$
		yes	no	$[-0.39, 0.39]$	$[-0.60, 0.13]$
		no	yes	$[-0.20, 0.21]$	$[-0.31, 0.07]$
		yes	yes	$[-0.20, 0.21]$	$[-0.31, 0.07]$

Submitted to EPJC arxiv.2603.22478

Limits on $c_{H\tilde{W}B}$: 2.5 times better than previous measurements using other final states!

Consistency observed in the CMS and ATLAS observations with full Run 2 data: no deviations from SM!

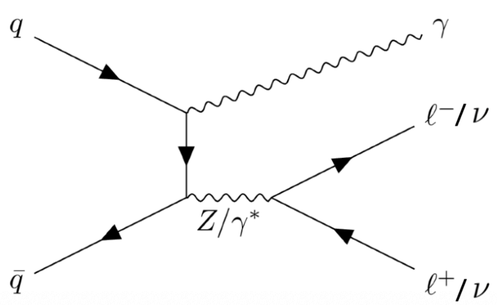


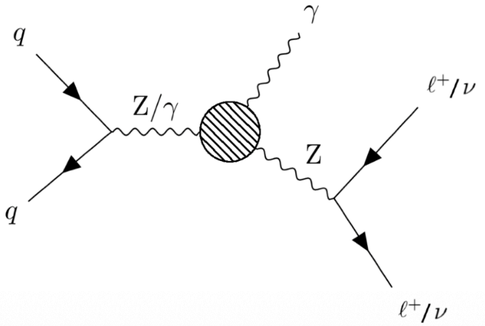
CMS Run 2 Result: PRD 105 (2022) 052003

$Z\gamma$ measurements (Run 3)

Process exploited for:

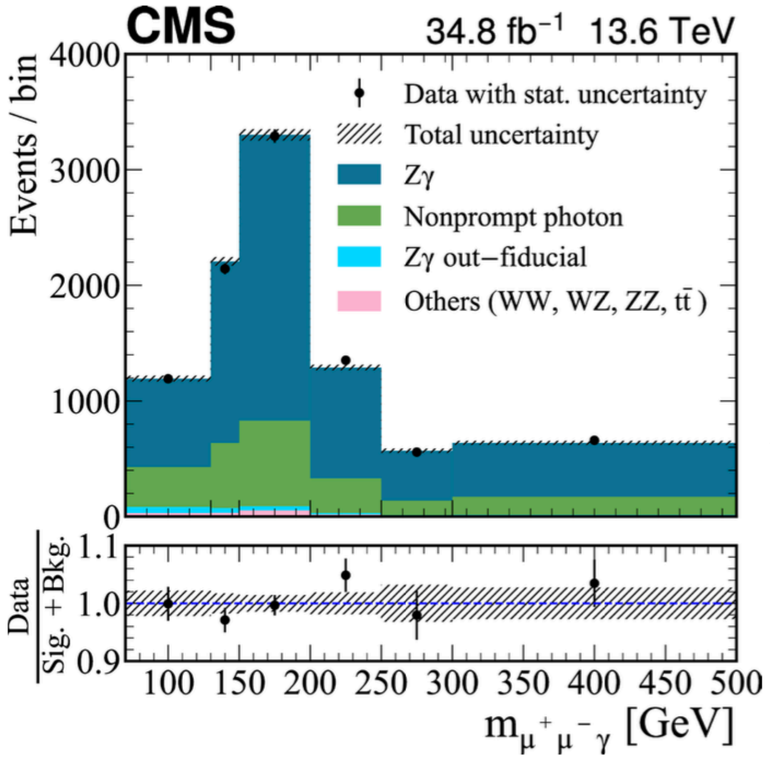
- differential measurements
- Search for anomalous neutral triple gauge couplings (aNTGC):
  - Measure excess/deficit from SM predictions.
  - Extending the SM Lagrangian.
  - Vertex functions describing the most general Lorentz and $U(1)_Y$ invariant interactions.





See M. Markovitch's talk for the detailed overview of the EFT interpretations.

Submitted to PRL
arxiv.2512.08582



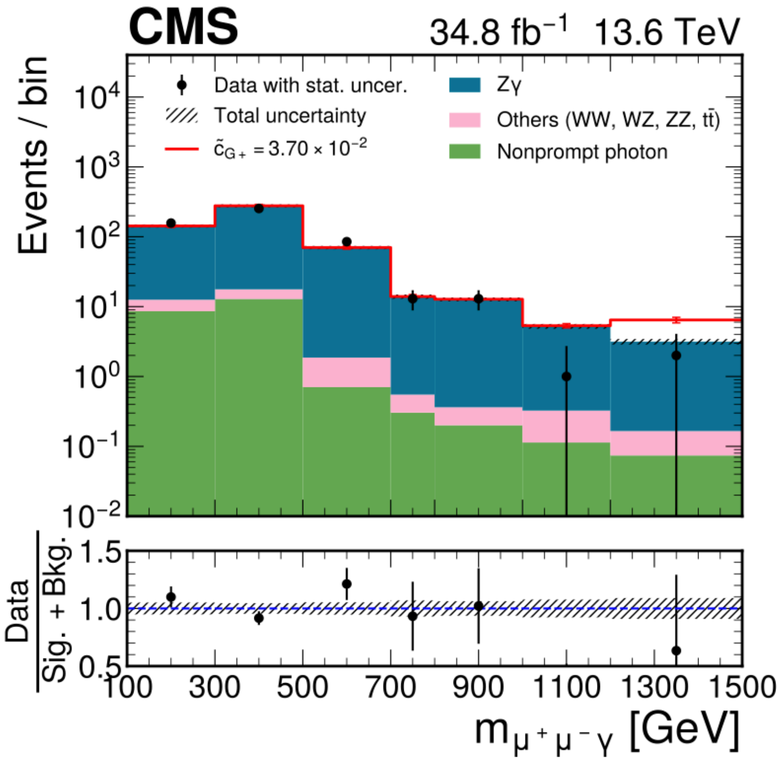
Channel	$\sigma\mathcal{B} \pm$ stat $\pm$ syst $\pm$ theo (pb)
$Z\gamma$ ($\mu\mu$)	$0.928 \pm 0.018 \pm 0.027 \pm 0.004$
$Z\gamma$ (ee)	$0.975 \pm 0.021 \pm 0.038 \pm 0.003$
$Z\gamma$ (combined)	$1.896 \pm 0.033 \pm 0.054 \pm 0.006$

Probing aNTGCs with dim-8 operators:

- preserving $SU(2)_L \times U(1)_Y$

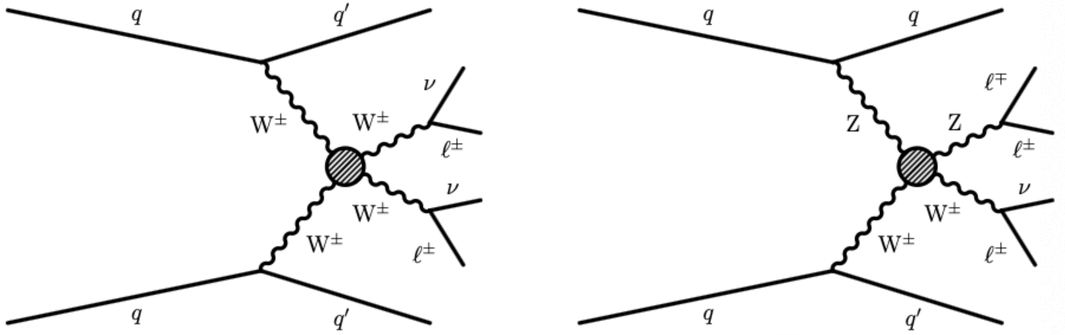
Limits	Expected		Observed	
	Lower	Upper	Lower	Upper
h_4^Z	-1.01×10^{-6}	1.01×10^{-6}	-8.17×10^{-7}	8.20×10^{-7}
h_3^γ	-8.34×10^{-4}	8.58×10^{-4}	-6.67×10^{-4}	6.88×10^{-4}
h_3^Z	-7.01×10^{-4}	6.96×10^{-4}	-5.69×10^{-4}	5.48×10^{-4}
$\tilde{c}_{G+}$	-3.83×10^{-2}	3.79×10^{-2}	-3.05×10^{-2}	3.06×10^{-2}
$\tilde{c}_{G-}$	-3.09	3.18	-2.44	2.54
$\tilde{c}_{\tilde{B}W}$	-1.24	1.26	-0.98	1.00

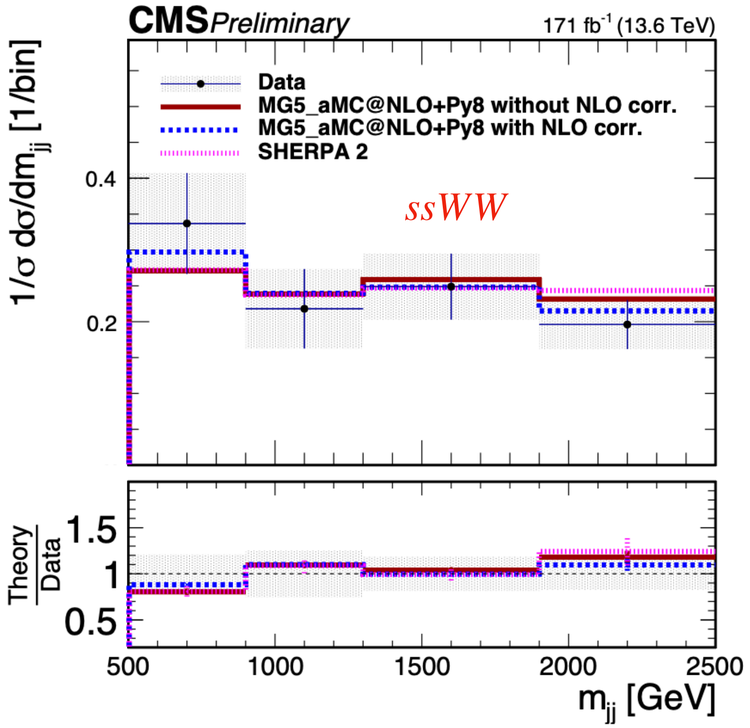
Probing these operators for the first time!

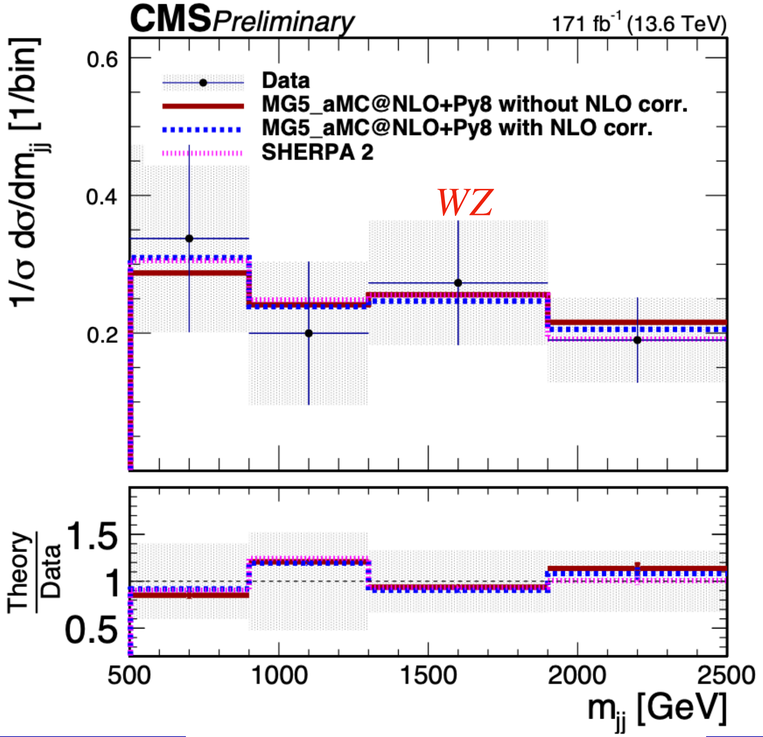


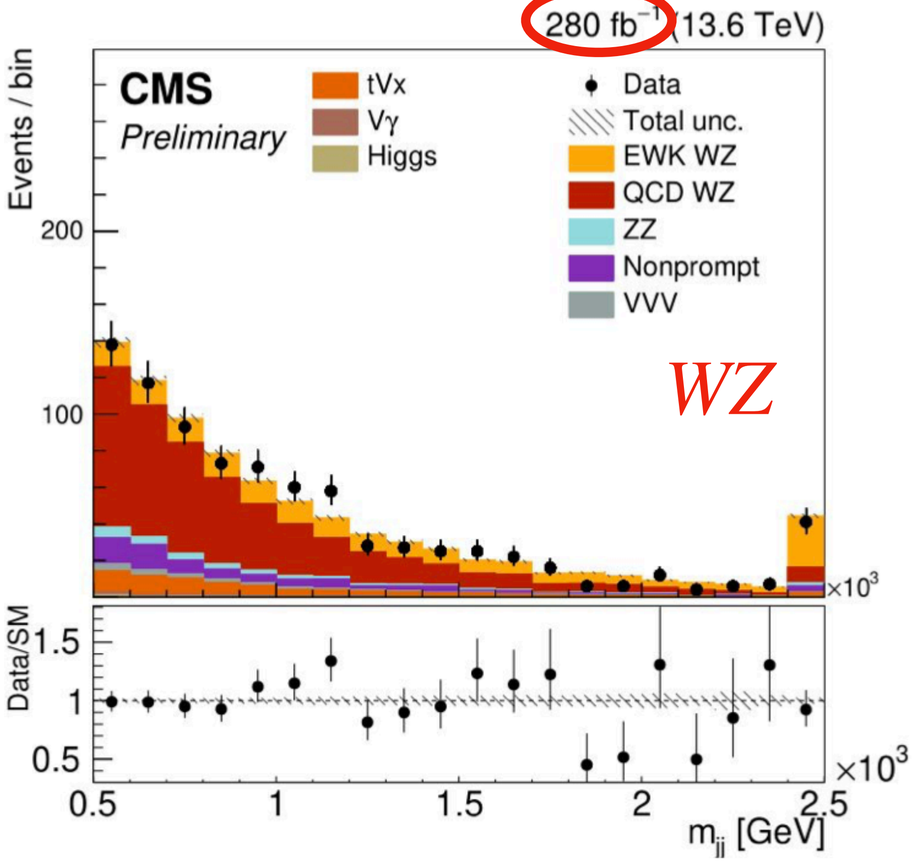
VBS: *ssWW* and *WZ* (Run 3)

- First VBS measurements with run-3 data: simultaneous measurement in same-sign $W(l\nu)W(l\nu)$ and $W(l\nu)Z(ll)$ final states.
- Differential fiducial cross sections as a function of several observables.
- The VBS topology is targeted by requiring $m_{jj} > 500$ GeV and $\Delta\eta_{ll} > 2.5$.
- Observation confirmed with run-3 (2022-24) data in both channels, at a **significance larger than 5σ each**! No evidence of deviations from SM.
- Latest 2025 data/MC plots.









CMS PAS SMP-25-013

VBS: ZZ+jj (Run 2)

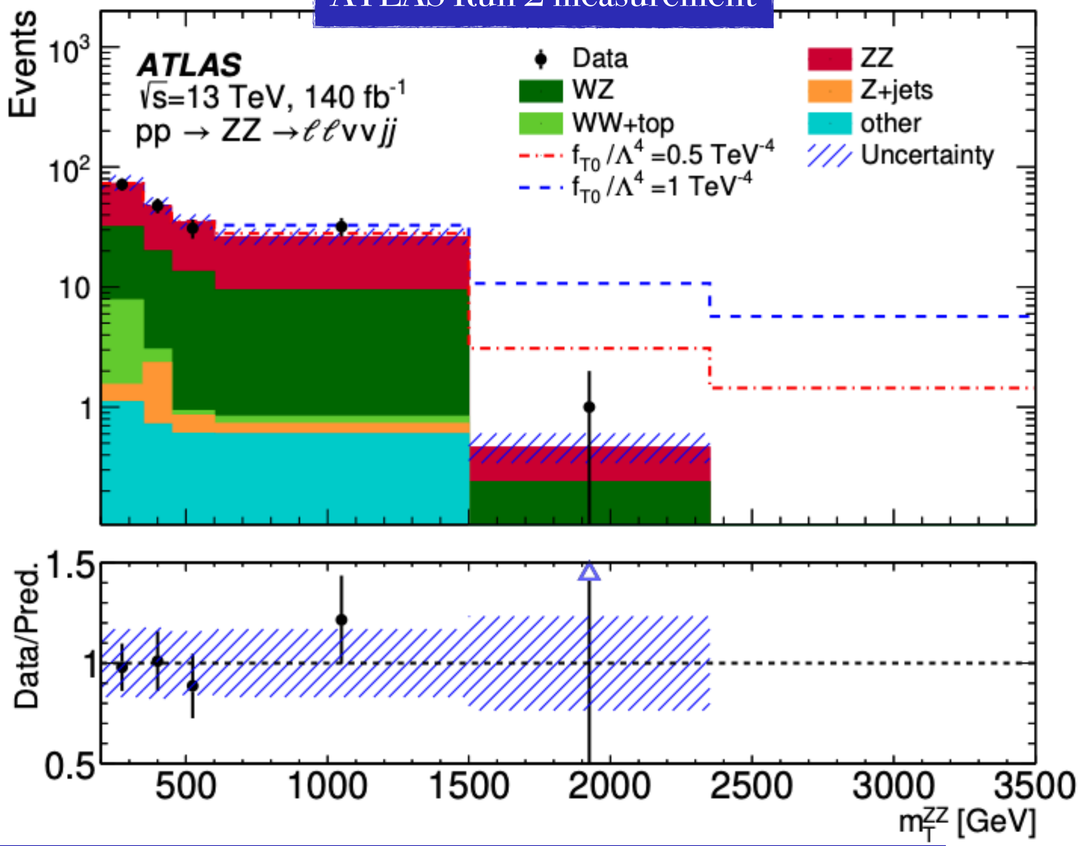
Recent ATLAS results:

- EW $ZZ + jj$ measurement observed from ATLAS 5.7σ in Run 2, Nature Phys. 19 (2023) 237.
- Differential measurement in Z(ll)Z($\nu\nu$) (inclusive and VBS enhanced), arxiv.2511.15569.

Recent CMS result:

- 3.1σ in $Z(ll)Z(\nu\nu) + jj$ with Run 2 dataset.
- combination with the previous $ZZ(4l) + jj$ result reaches 5σ.

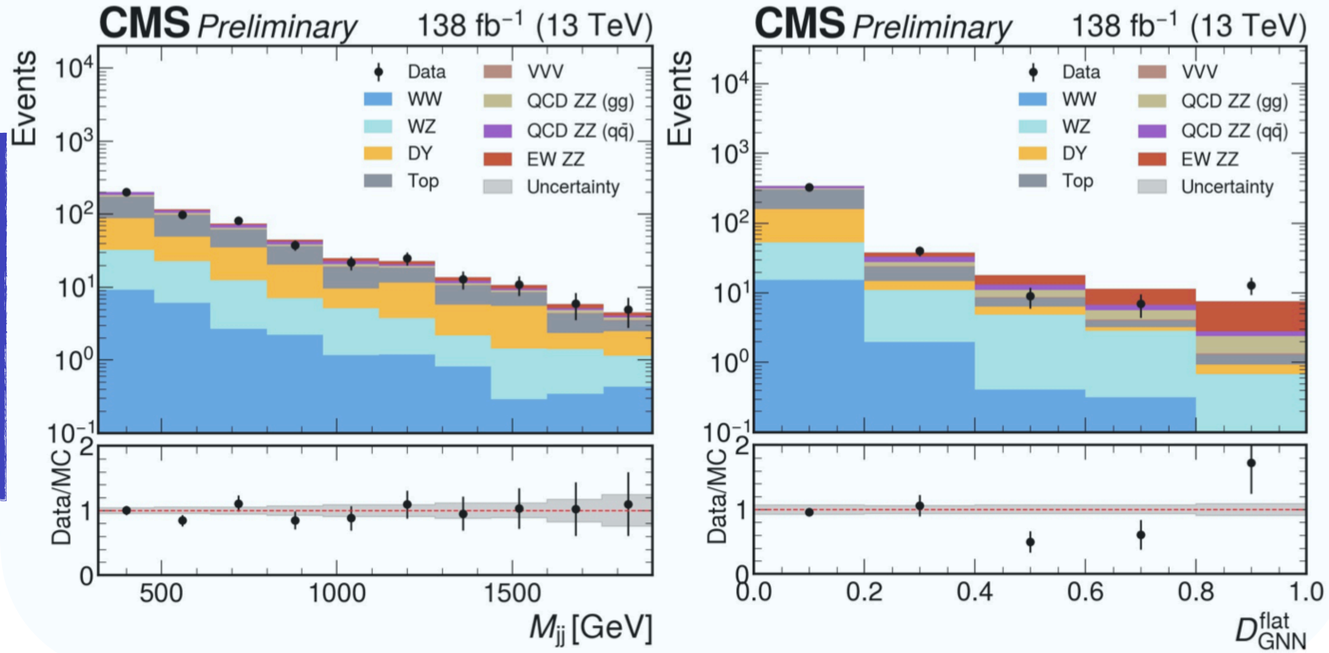
ATLAS Run 2 measurement



CMS Run 2 measurement

CMS PAS SMP-23-001

To enhance the separation of the rare EW ZZ signal from backgrounds, GNN based multivariate discriminator is used.

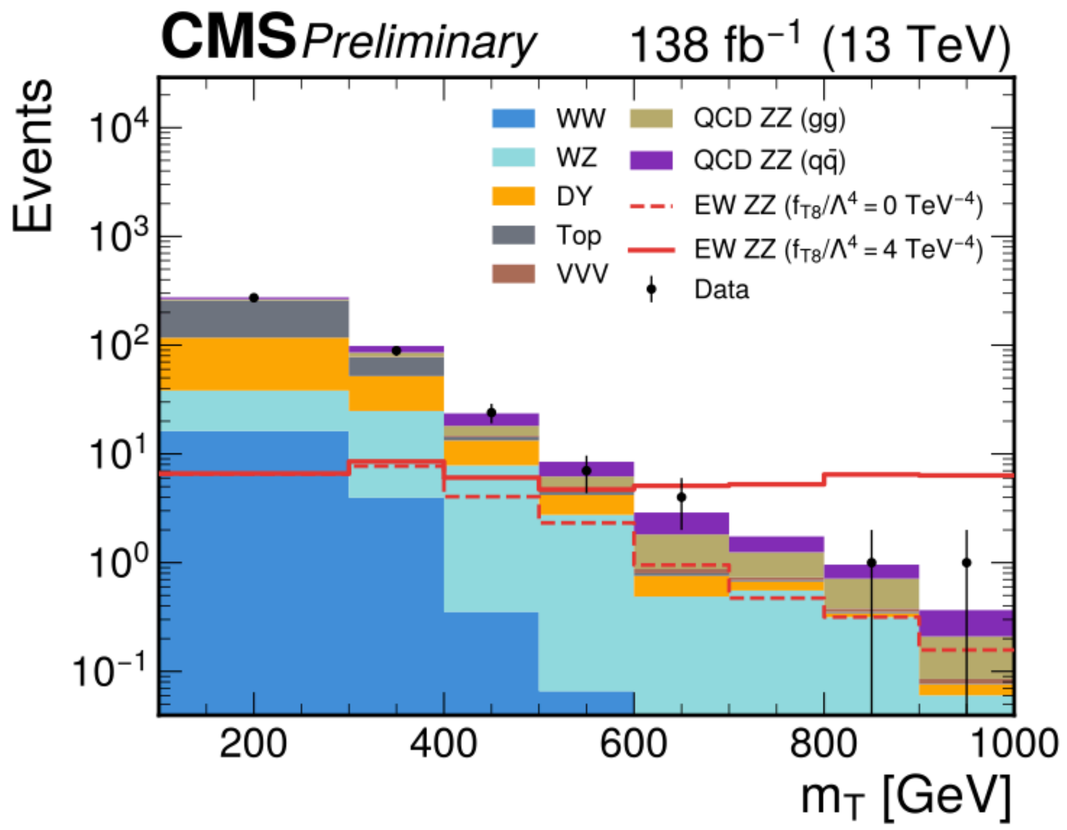


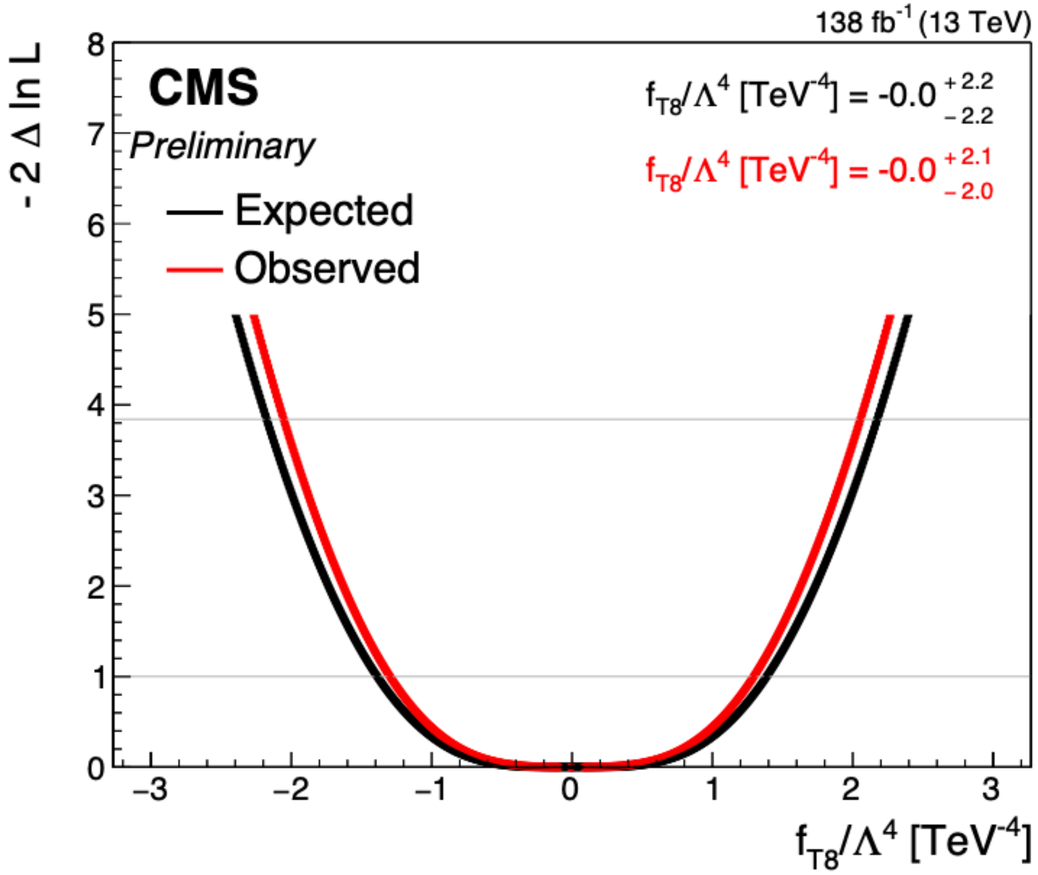
VBS: ZZ+jj (Run 2)

Recent CMS result:

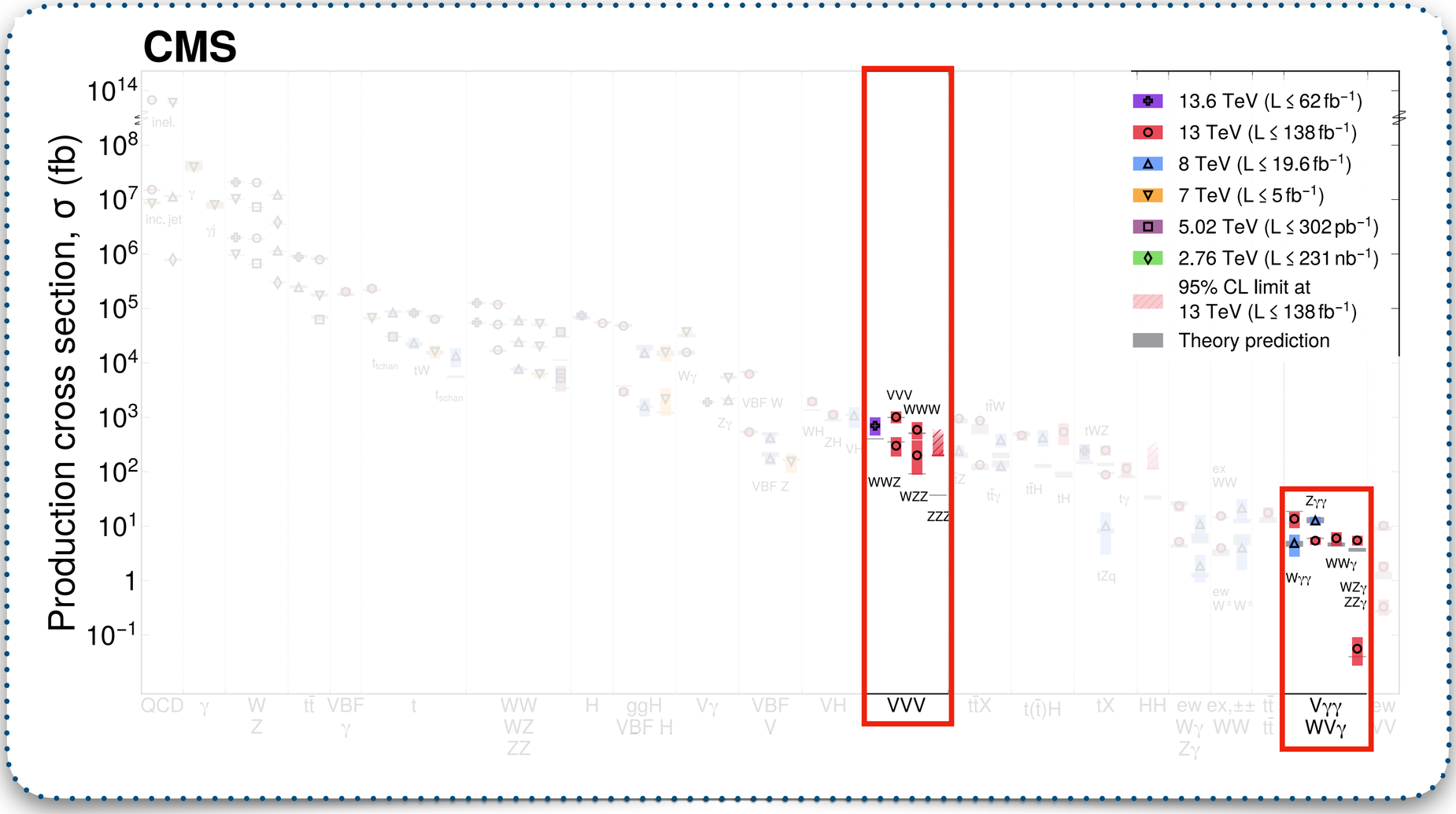
- Maximum likelihood estimator to derive two-sided 95% confidence intervals on the couplings f_i/Λ^4 of dim. 8 operators describing anomalous quartic gauge interactions.
- No deviations from SM predictions observed.

CMS PAS SMP-23-001



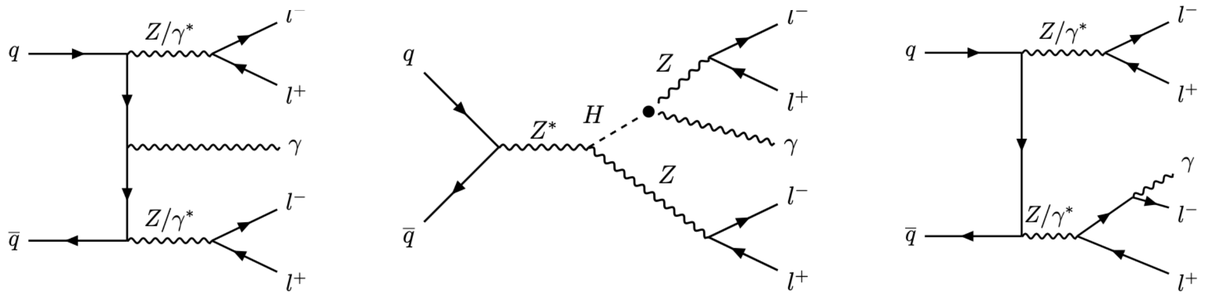


Triboson measurements: $ZZ\gamma$, WWZ



$ZZ\gamma$ measurements (Run 2)

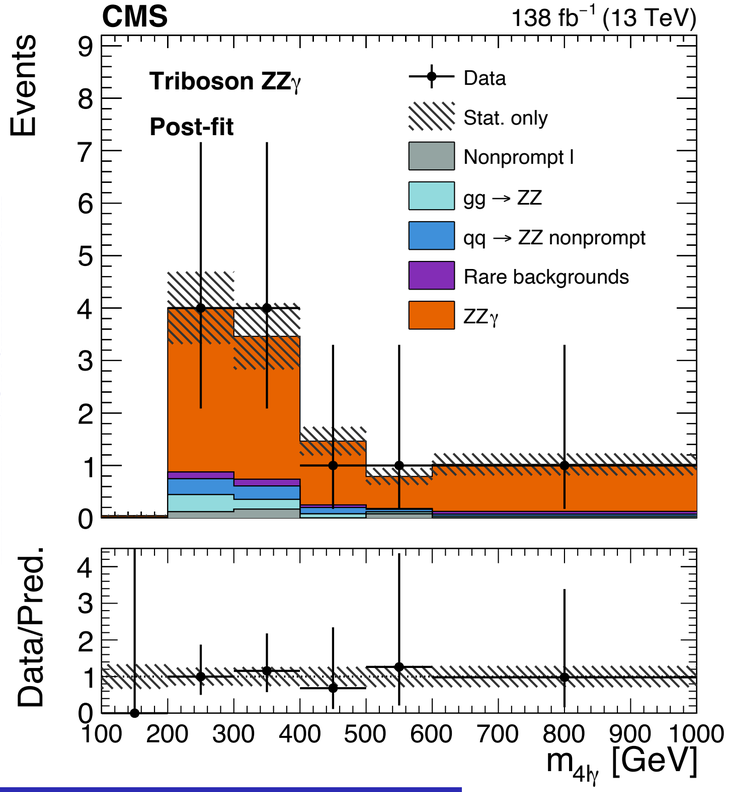
- Search for the SM production of $ZZ\gamma$: statistically limited.
- **Evidence from CMS**: $\mathbf{3.7}\sigma$ last year.
- **Evidence from ATLAS**: $\mathbf{4.4}\sigma$ this year.
  - Profile likelihood fit, three 1-bin SRs combining the $4e, 2e2\mu, 4\mu$ channels done by ATLAS.



See A. Ackermann's talk for the detailed overview of the ATLAS analysis.

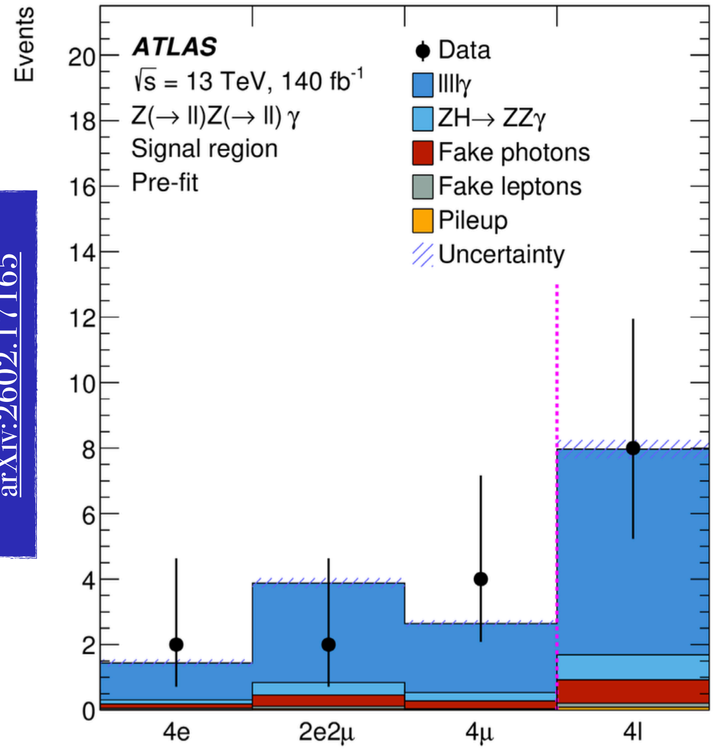
$\sigma_{ZZ\gamma} = 0.06 \pm 0.03$ fb

Submitted to PRL: arxiv.2604.02594



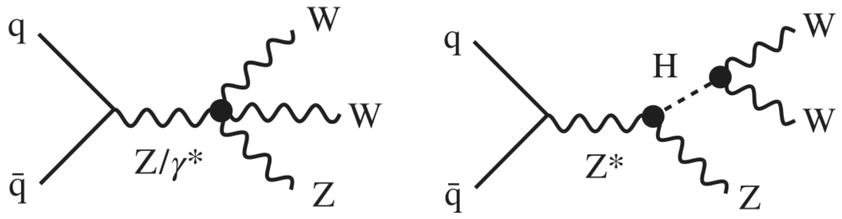
$\sigma_{ZZ\gamma} = 0.144^{+0.064}_{-0.051}(stat.)^{0.007}_{-0.005}(syst)$ fb

arXiv:2602.17165

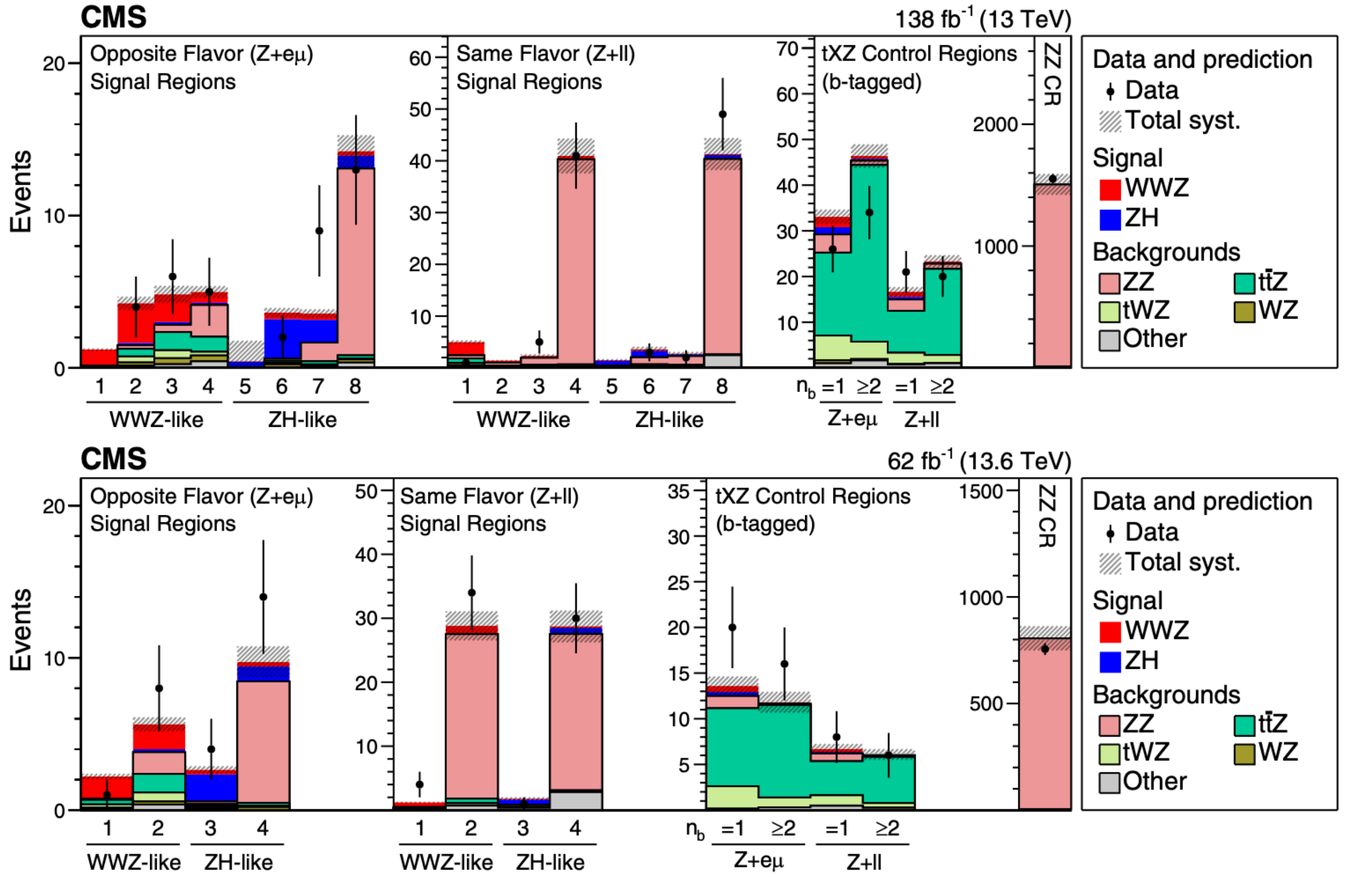


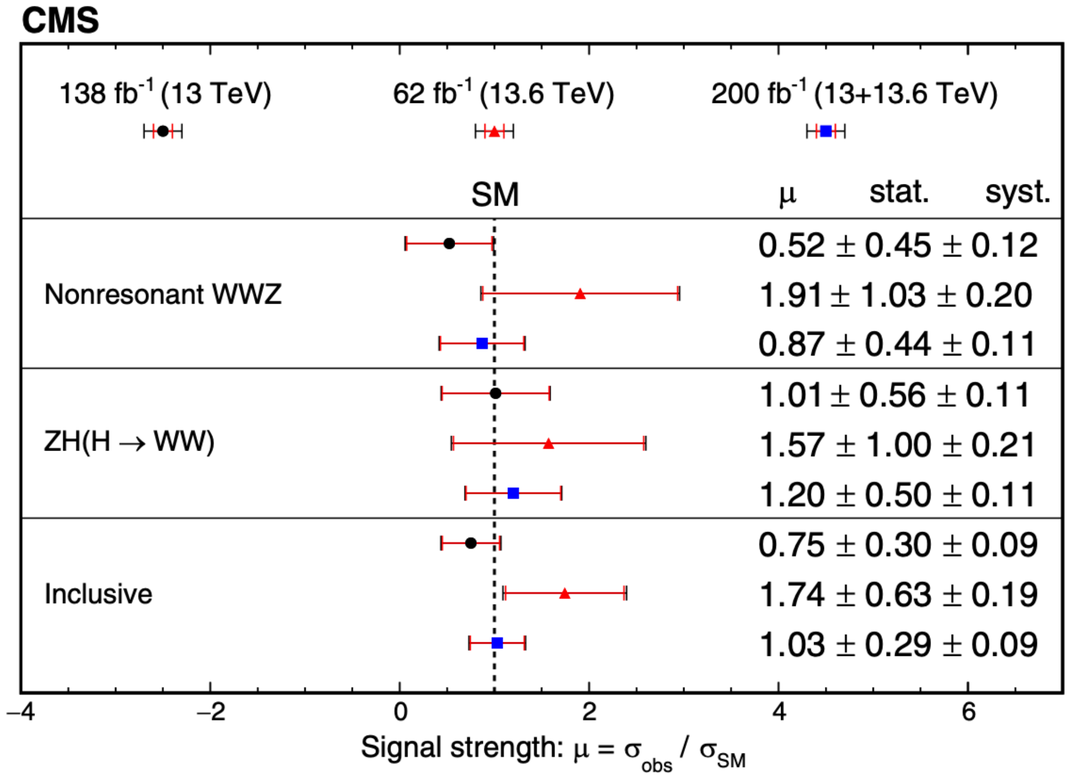
WWZ measurements (Run 2 + Run 3)

- Separate and simultaneous measurement of *WWZ* and *HZ*.
- Evidence for triboson production with 4.5σ (5σ) observed (expected) significance.
- ATLAS confirms the evidence of WWZ with 4.4σ (3.6σ) observed (expected) significance (Phys. Lett. B 866 (2025) 139527) with Run 2 dataset.



PRL 135 (2025) 091802





Summarising

- Diboson measurements validate the electroweak sector.
- VBS now observed in several channels and probes electroweak symmetry breaking.
- First Run-3 VBS measurements at $\sqrt{s} = 13.6$ TeV.
- Triboson and radiative processes extend sensitivity to rare gauge interactions.
- Run-3 and HL -LHC will transform multiboson physics into a precision probe of the electroweak sector.

*CMS only

*ATLAS only

*Both

From the ATLAS side

- $W\gamma$: arxiv.2603.22478 (Run 2)
- VBS ZZ: arxiv.2511.15569 (Run 2)
- $ZZ\gamma$: arXiv:2602.17165 (Run 2)

From the CMS side

- $Z\gamma$: arXiv:2512.08582 (Run 3), arXiv:2601.14102 (Run 2)
- *ssWW* and *WZ* : arXiv:2601.21574 (Run 3)
- VBS ZZ: CMS PAS SMP-23-001(Run 2)
- *WWZ* : PRL 135 (2025) 091802 (Run 3 + Run 2)

More multibosons:

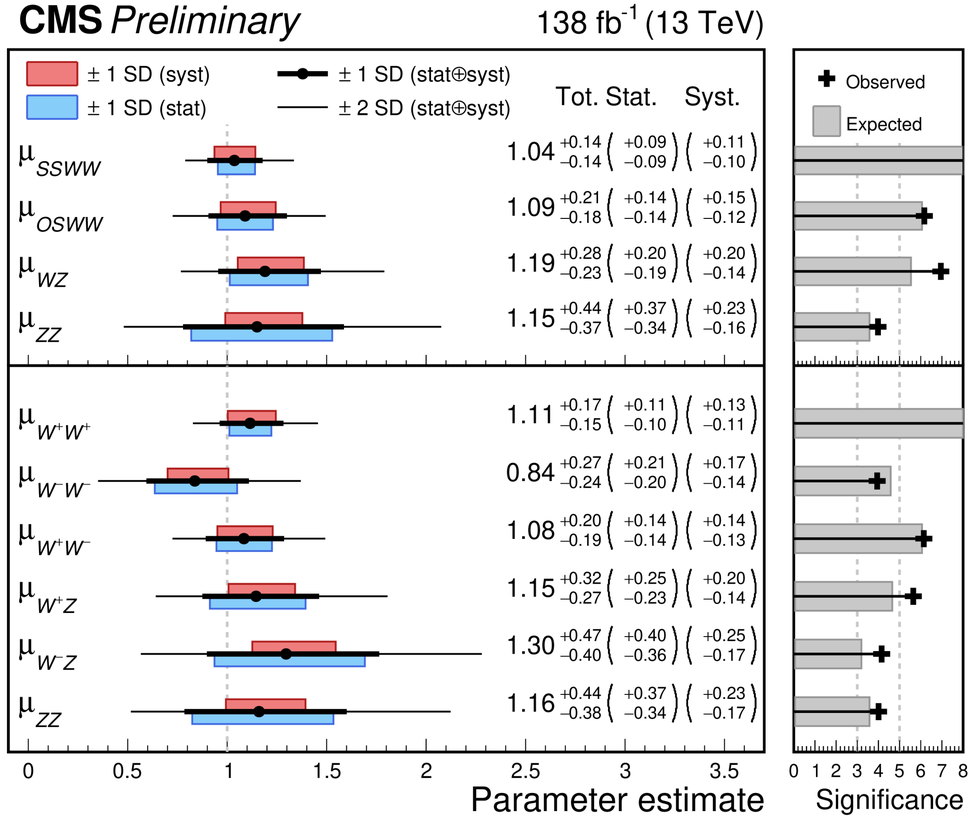
1. VBS combination
2. Recent WZ results
3. Recent ZZ results
4. Recent WW results

Thank you!

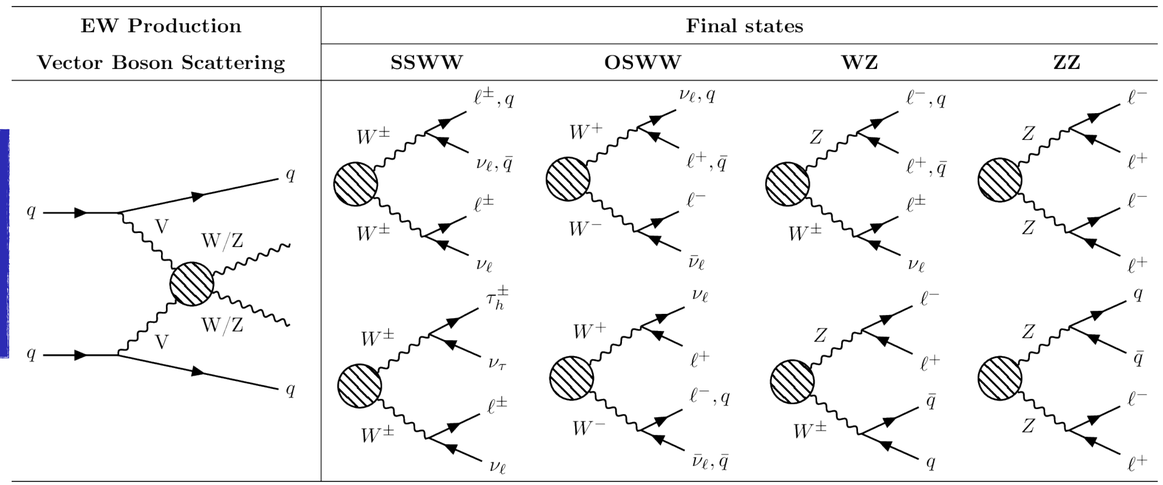
VBS: CMS combination across 7 channels (Run 2)

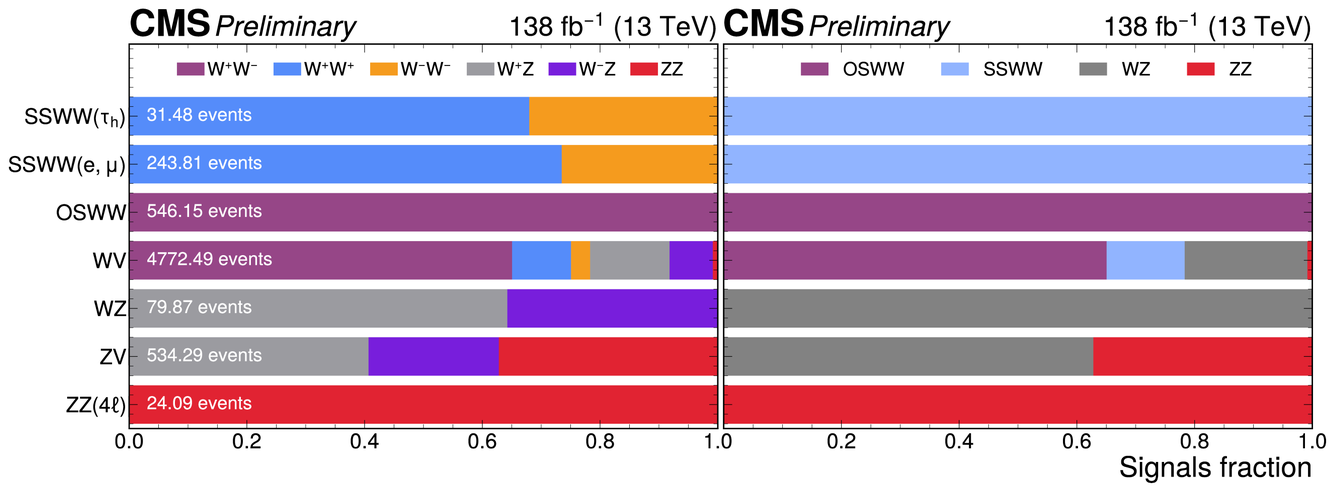
- Simultaneous fit to fully-leptonic ($ssWW, osWW, WZ, ZZ$) and semi-leptonic (WV, ZV) final states - 7 channels!
- Measured μ values (4-POI model) are all consistent with 1 within uncertainties
- Provides a coherent baseline for EFT / aQGC interpretations.

CMS PAS-SMP-24-013



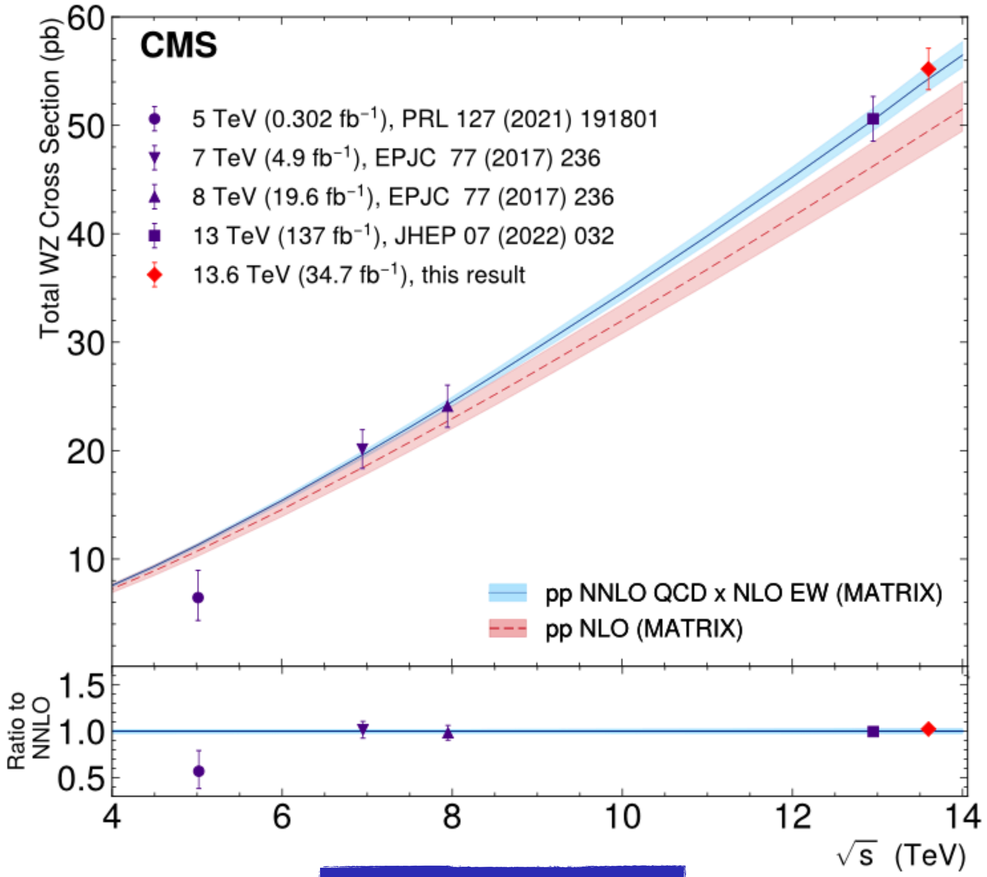
VBS Topologies



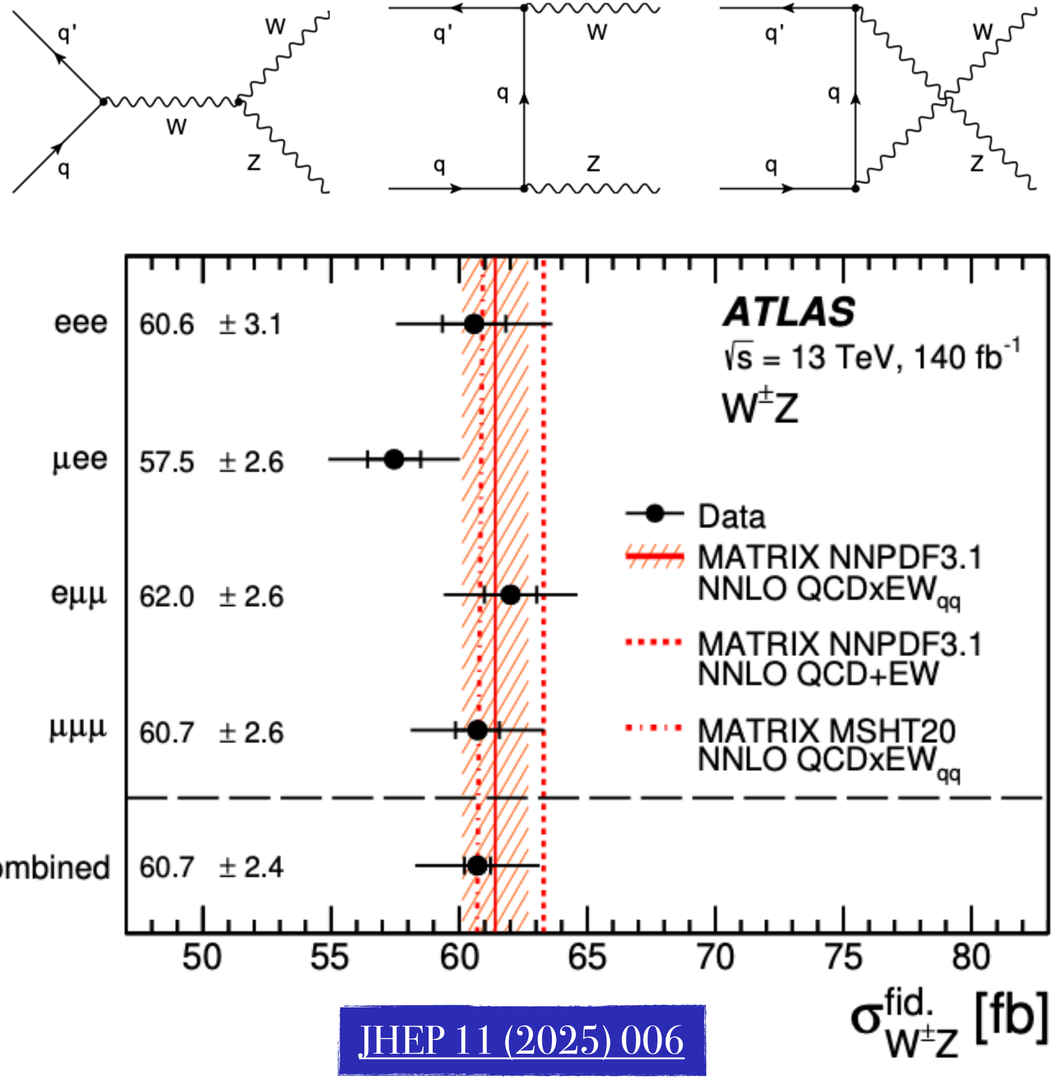


See Mathieu Markovitch's talk for the latest ATLAS EFT dim. 8 combination results.

WZ measurements

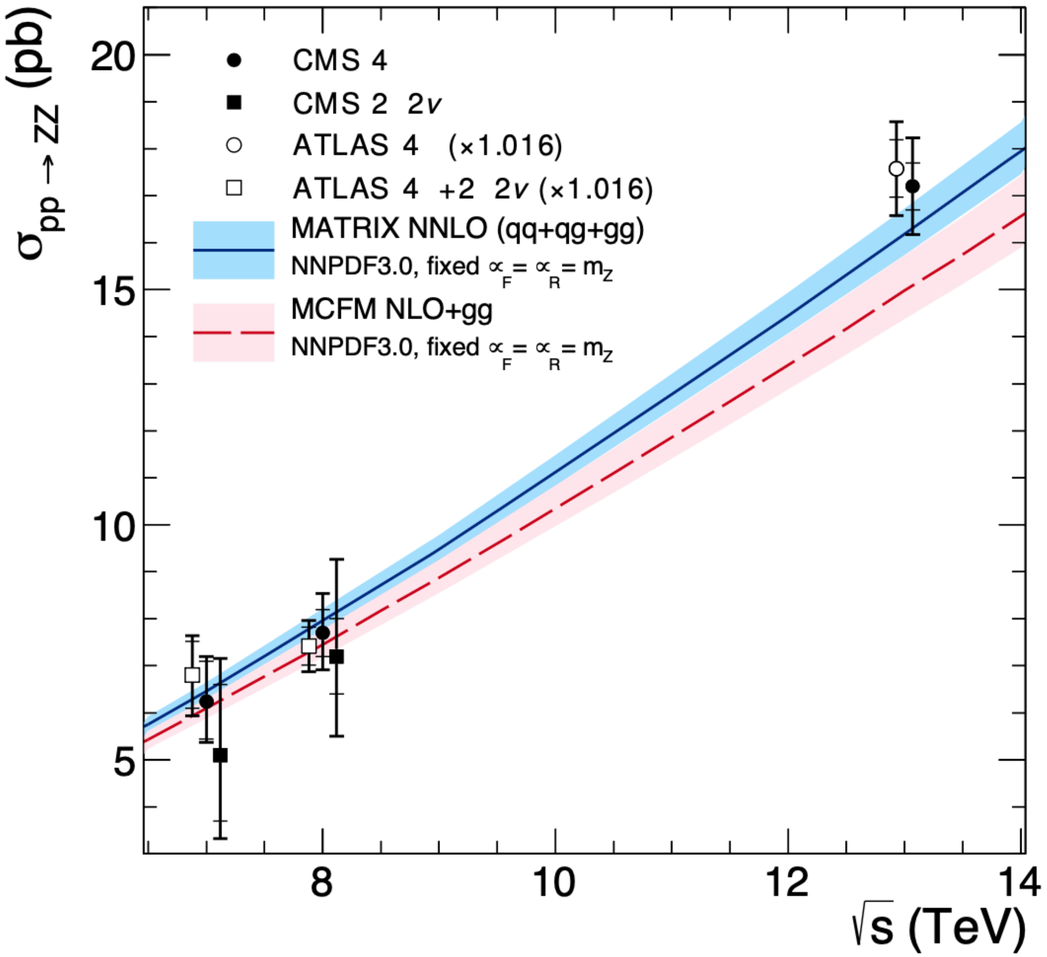


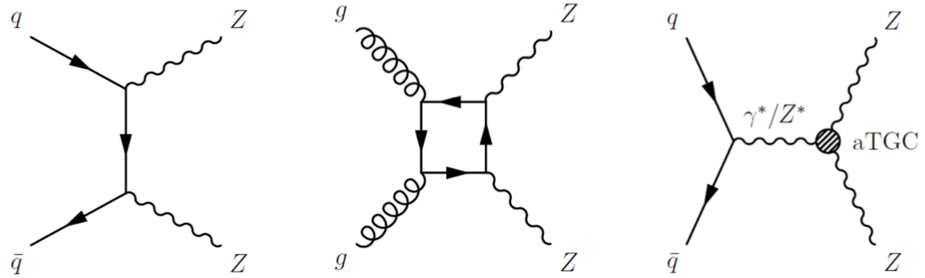
JHEP 04 (2025) 115

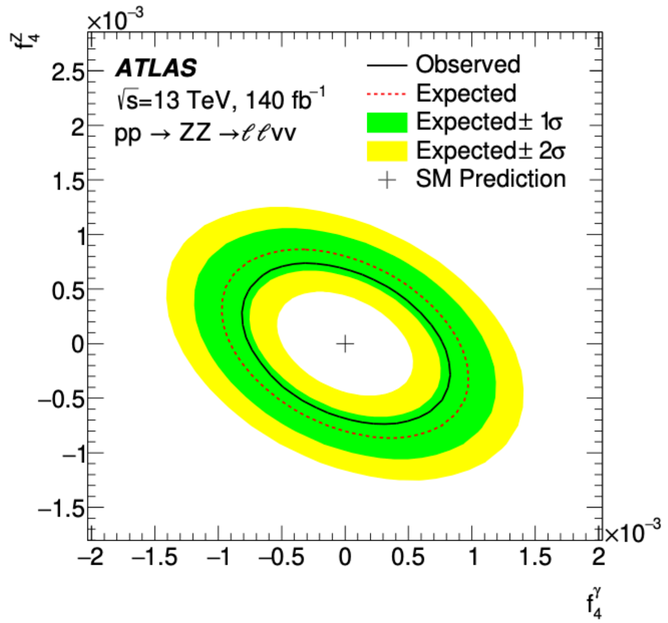


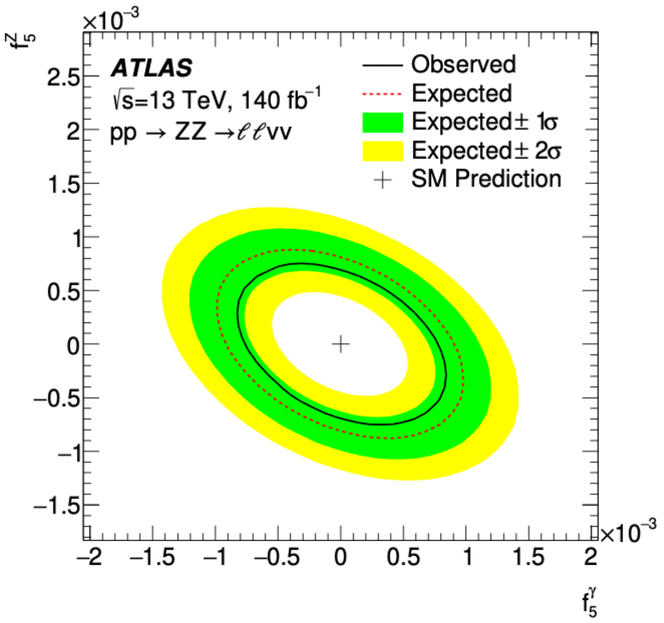
JHEP 11 (2025) 006

ZZ measurements









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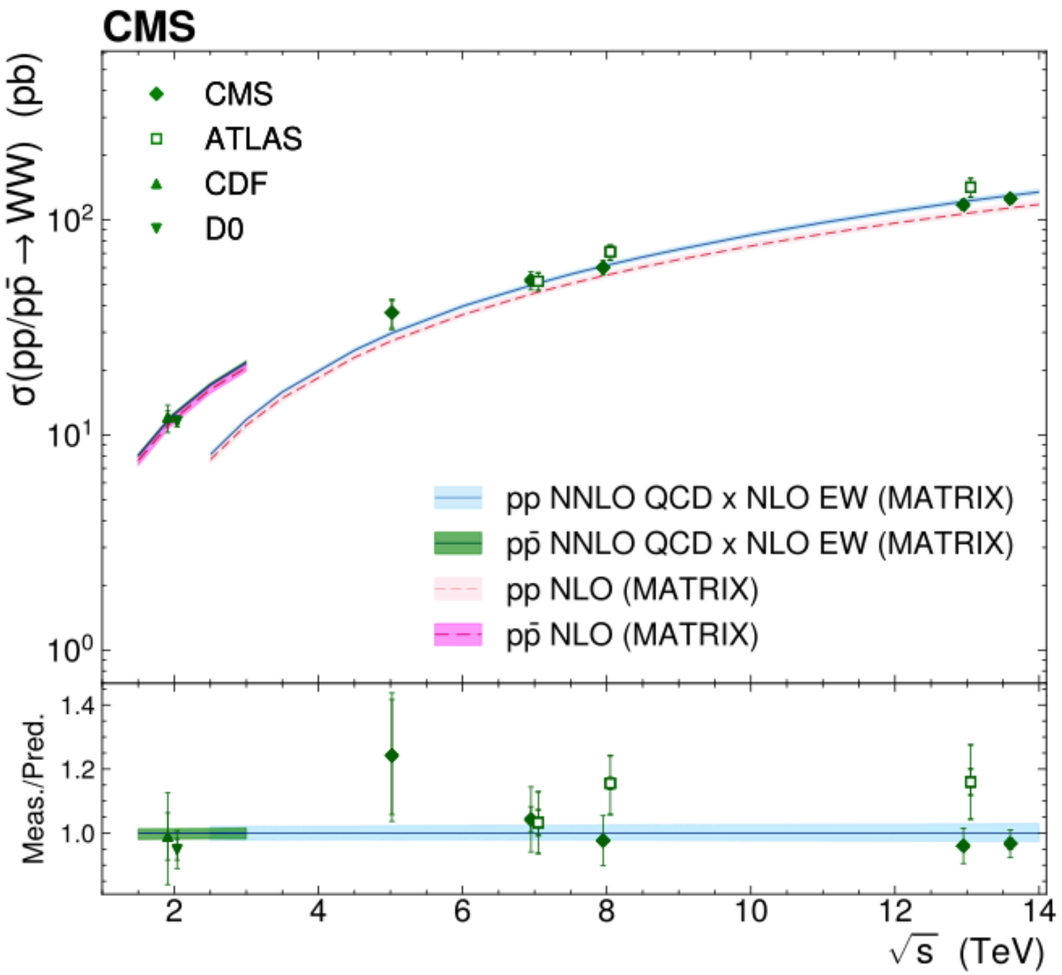
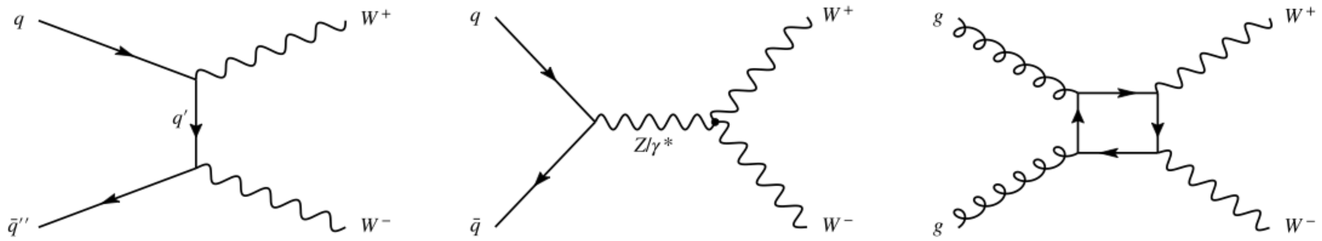
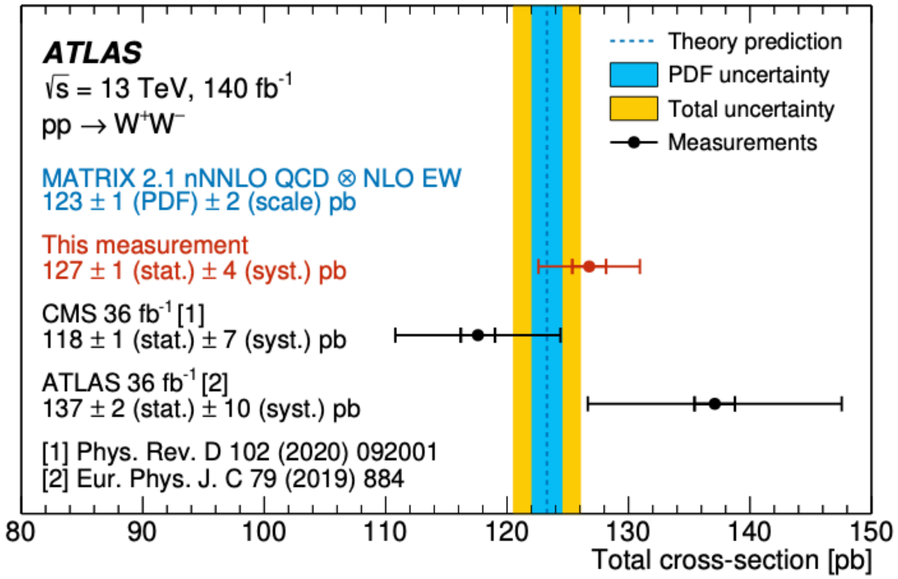
WW measurements







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