

Recent results on VBF and diboson production

Emmanuel Sauvan

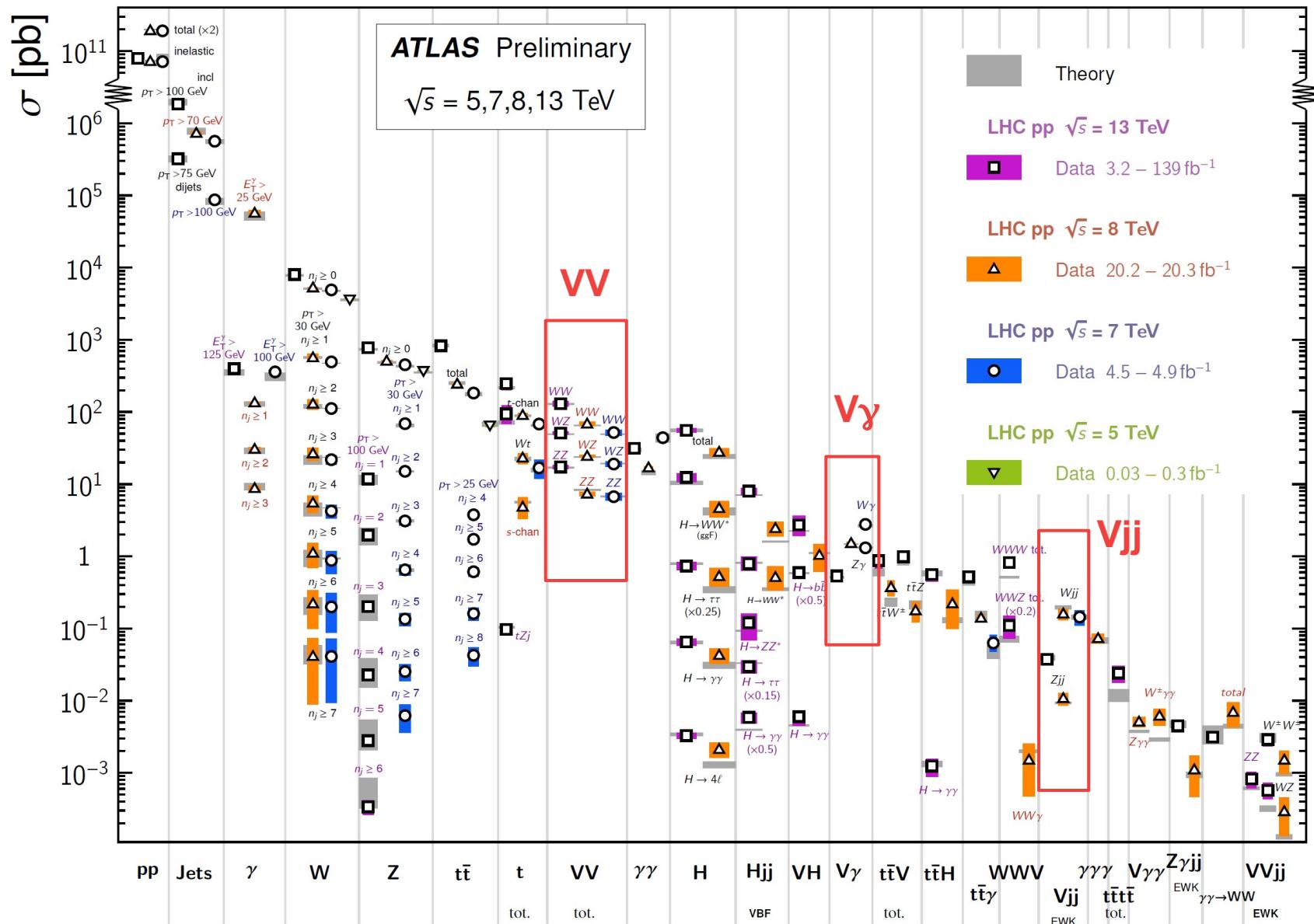
LAPP Annecy
CNRS/IN2P3 et Université Savoie Mont Blanc

On behalf of LHC Collaborations

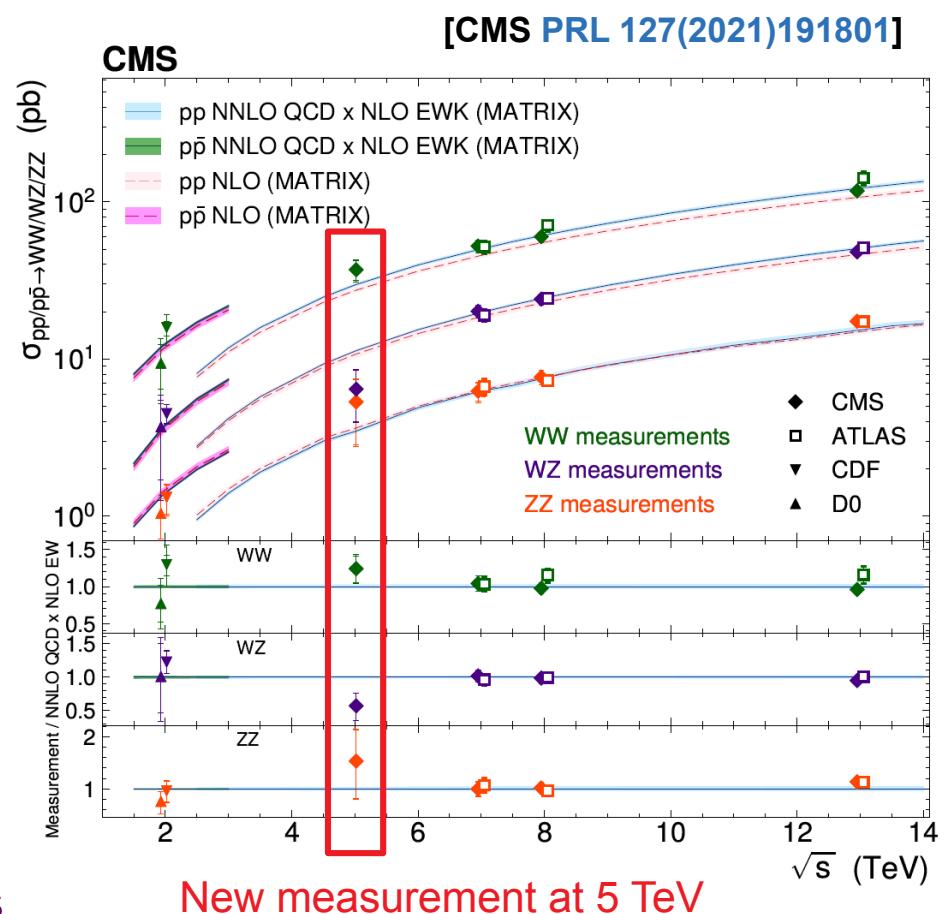
The landscape

Standard Model Production Cross Section Measurements

Status: February 2022



- Precision era now with full LHC run2 data
 - Precision of measurements pushed forward theory developments
 - Theory predictions at NNLO QCD + NLO EW
- Experimental goal: full metrology of diboson processes
 - Test theory predictions
 - Differential cross sections
 - More or new observables
 - More complex phase spaces
- Challenges: systematics and model uncertainties
 - Precision of MC generators



- New physics constraints via Effective Field Theory

$$\mathcal{L}_{\text{SMEFT}} \approx \mathcal{L}_{\text{SM}}^{(4)} + \left[\sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} \right] + \sum_j \frac{c_j^{(8)}}{\Lambda^4} O_j^{(8)}$$

$$\sigma \propto |\mathcal{M}_{\text{SMEFT}}|^2$$

$$\begin{aligned}
 &= |\mathcal{M}_{\text{SM}}|^2 + \sum_i \frac{c_i^{(6)}}{\Lambda^2} 2\text{Re}(\mathcal{M}_i^{(6)} \mathcal{M}_{\text{SM}}^*) + \sum_i \frac{(c_i^{(6)})^2}{\Lambda^4} |\mathcal{M}_i^{(6)}|^2 + \sum_{i < j} \frac{c_i^{(6)} c_j^{(6)}}{\Lambda^4} 2\text{Re}(\mathcal{M}_i^{(6)} \mathcal{M}_j^{(6)*}) \\
 &\quad + O(\Lambda^{-4}),
 \end{aligned}$$

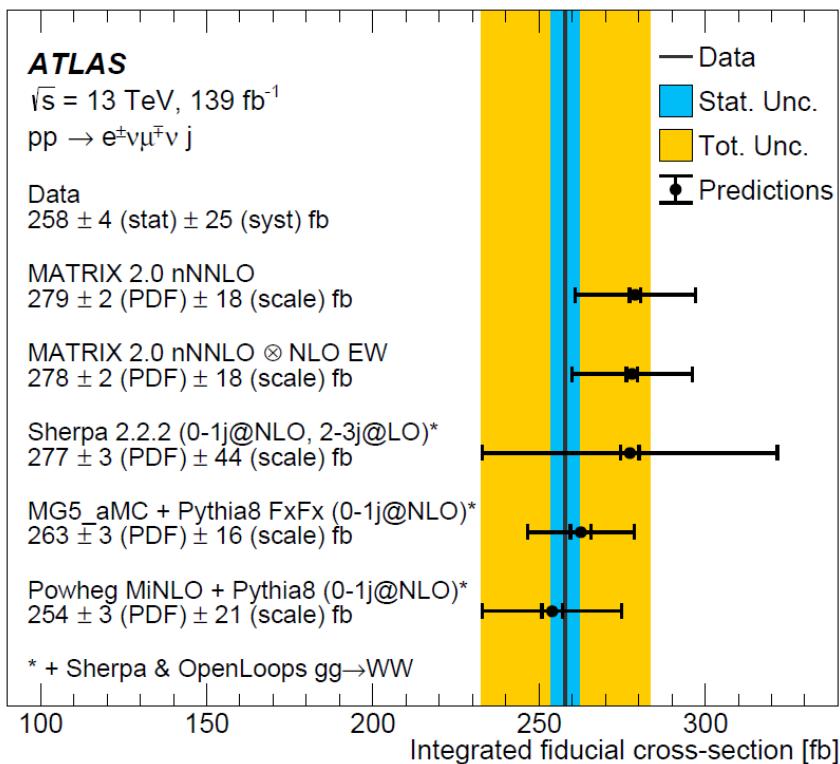
leading:
 Interference
 (linear terms) sub-leading:
 quadratic terms cross terms
 Also contains interference with dim. 8

- For dibosons, SM/BSM interference is suppressed
 - Due to different helicity configurations for SM and BSM
 - Can be restored using angular variables or jets

[e.g. arXiv:1707.08060, arXiv:1708.07823]

➔ Can we neglect dim. 8 in EFT interpretations for diboson ?

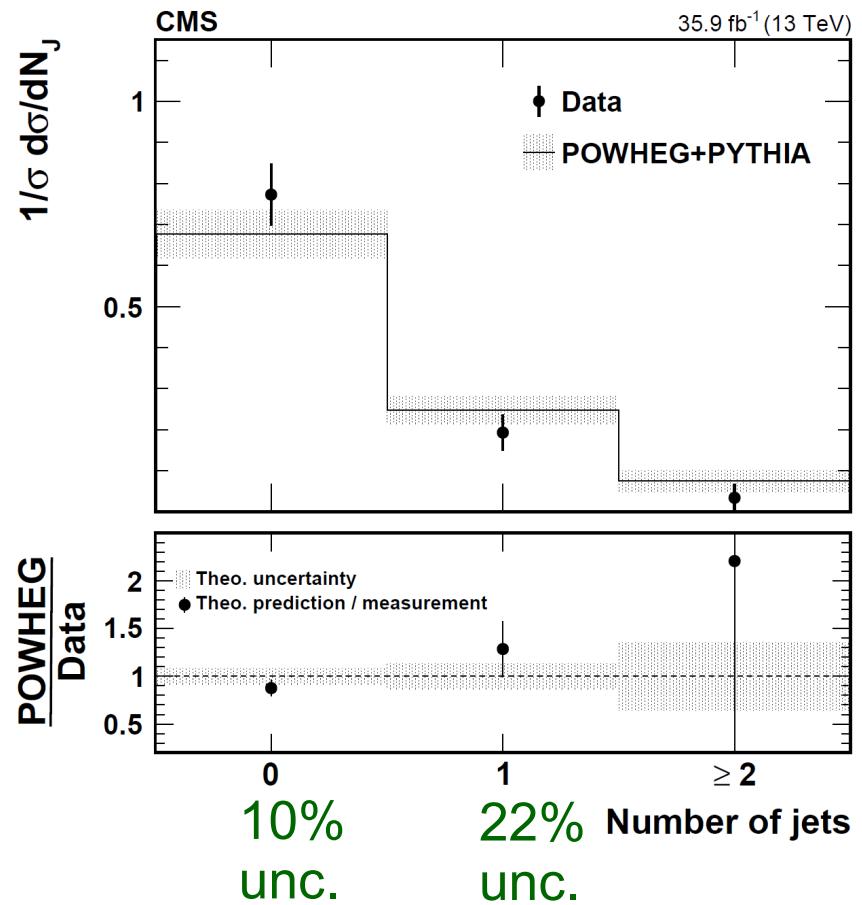
- WW + ≥ 1 jet
 - So far limited to WW+0 or 1 jet, to reduce background
 - Now in a jet-inclusive phase space



→ 10% precision

(139 fb-1) (36 fb⁻¹)

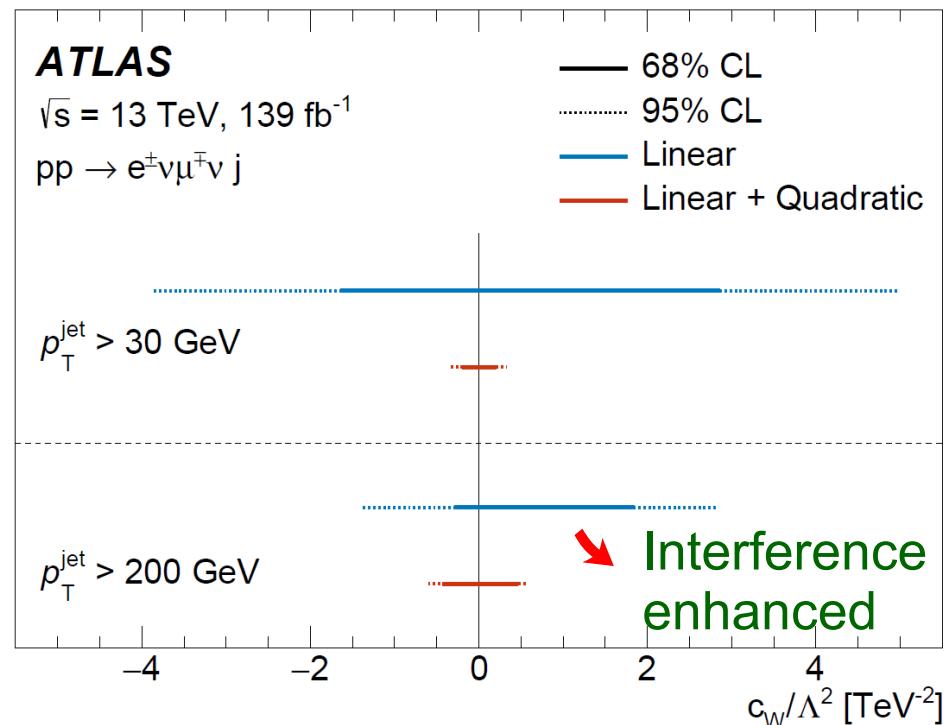
- Inclusive WW
 - Uses random-forest classifiers to reduce top background
 - Allows to measure jet multiplicity



- WW + ≥ 1 jet

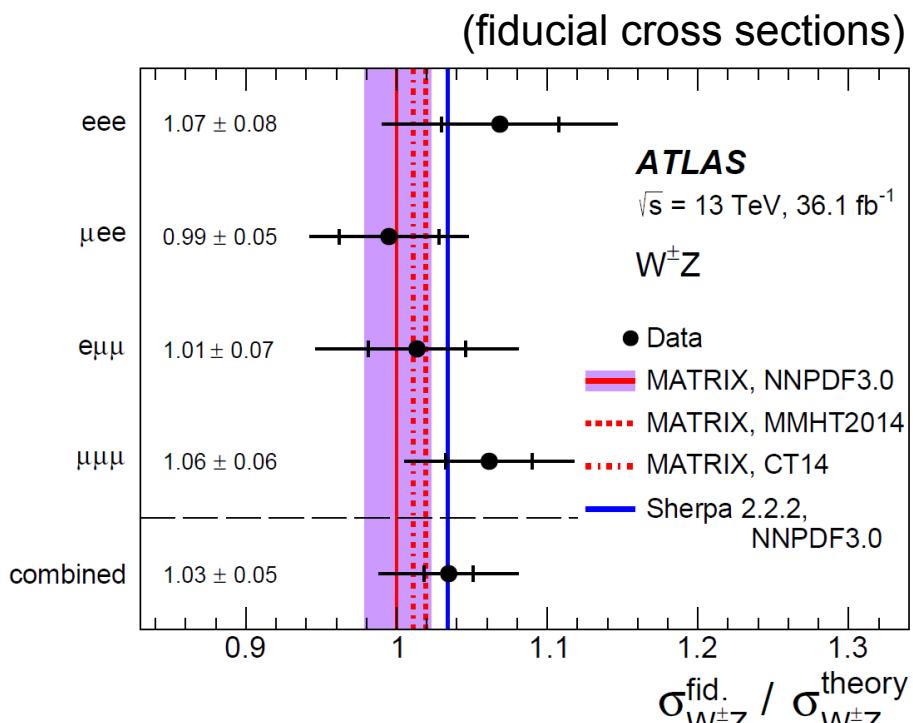
→ Requirement of hard jets probes different helicity configuration
→ Restore SM/BSM interference

[arXiv:1707.08060]



→ Quadratic still dominant

- Large inclusive phase space
 - No direct cut on E_T^{miss} , but on m_T^W

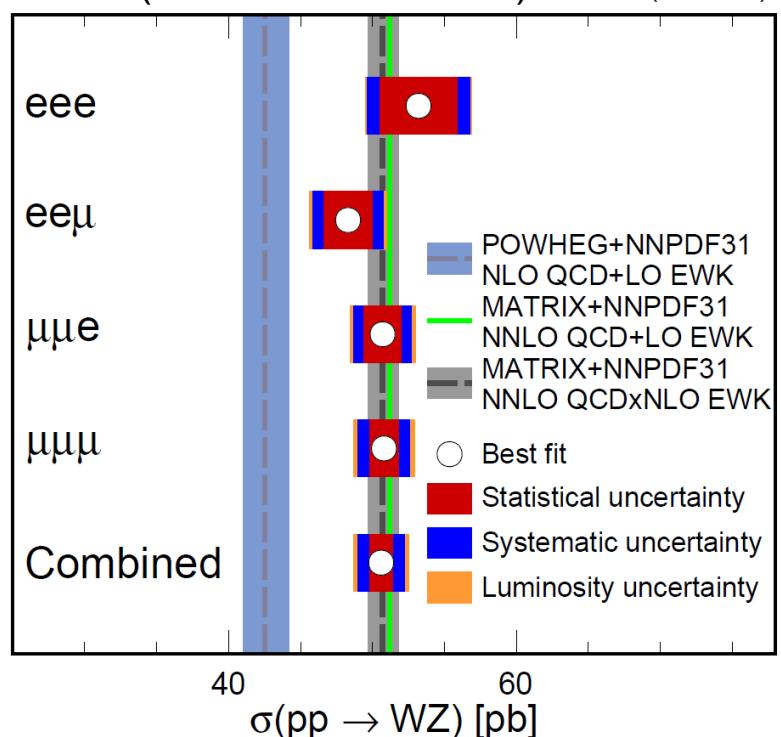


↘ 4.5% precision

(36 fb $^{-1}$) (137 fb $^{-1}$)

- More restricted phase space
 - b-jets veto

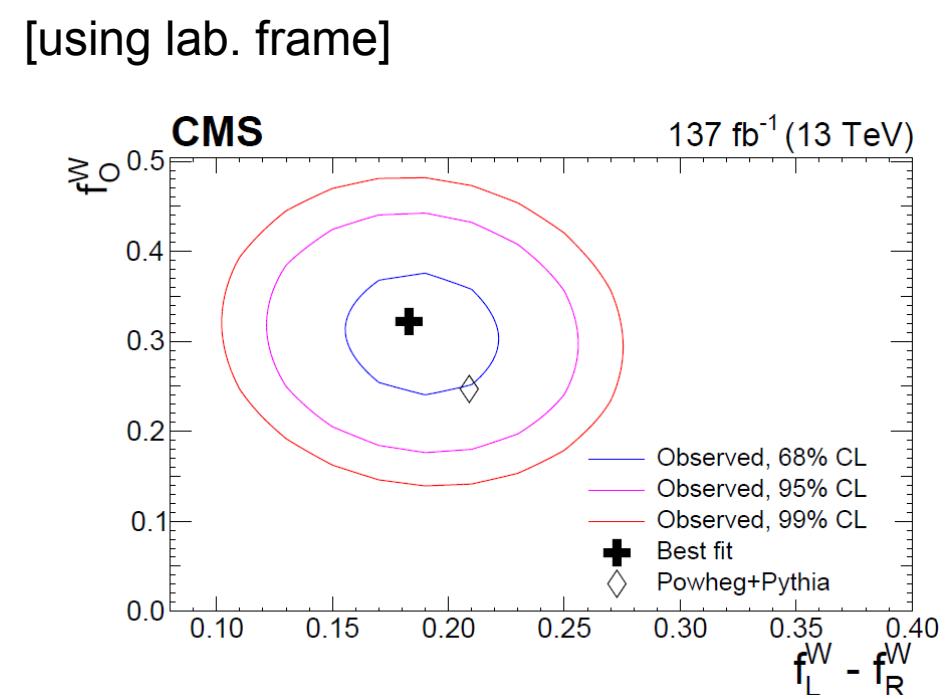
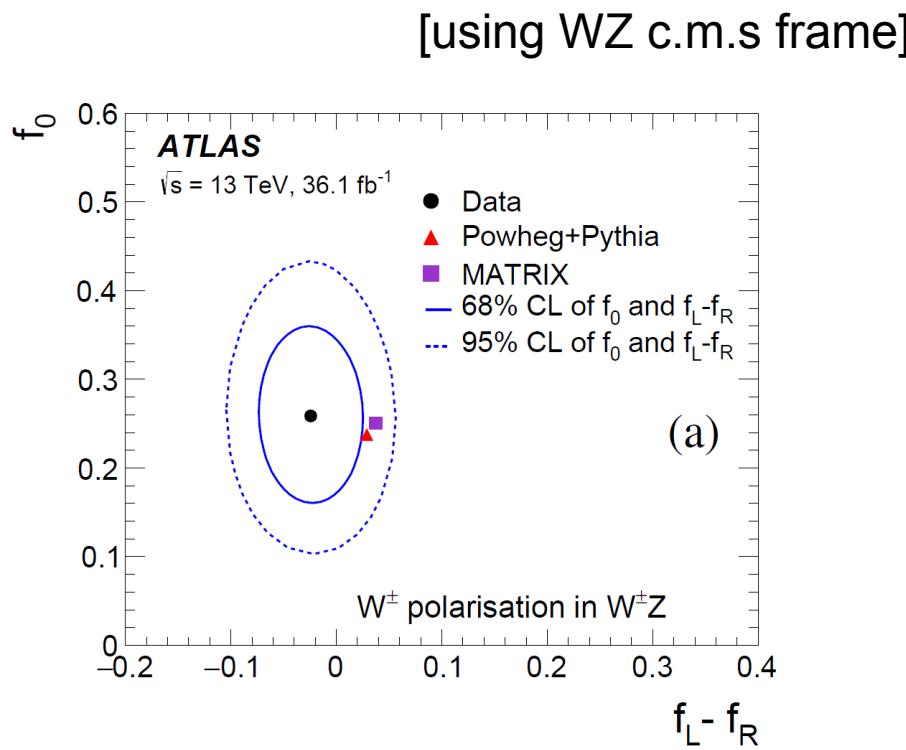
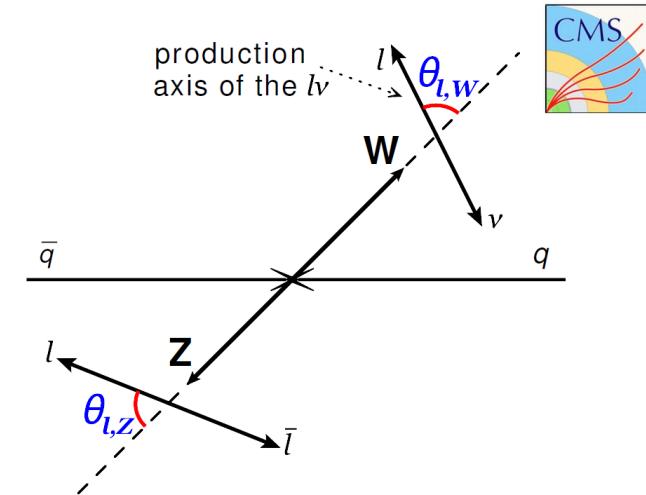
CMS (total cross sections) 137 fb $^{-1}$ (13 TeV)



↘ 3.6% precision

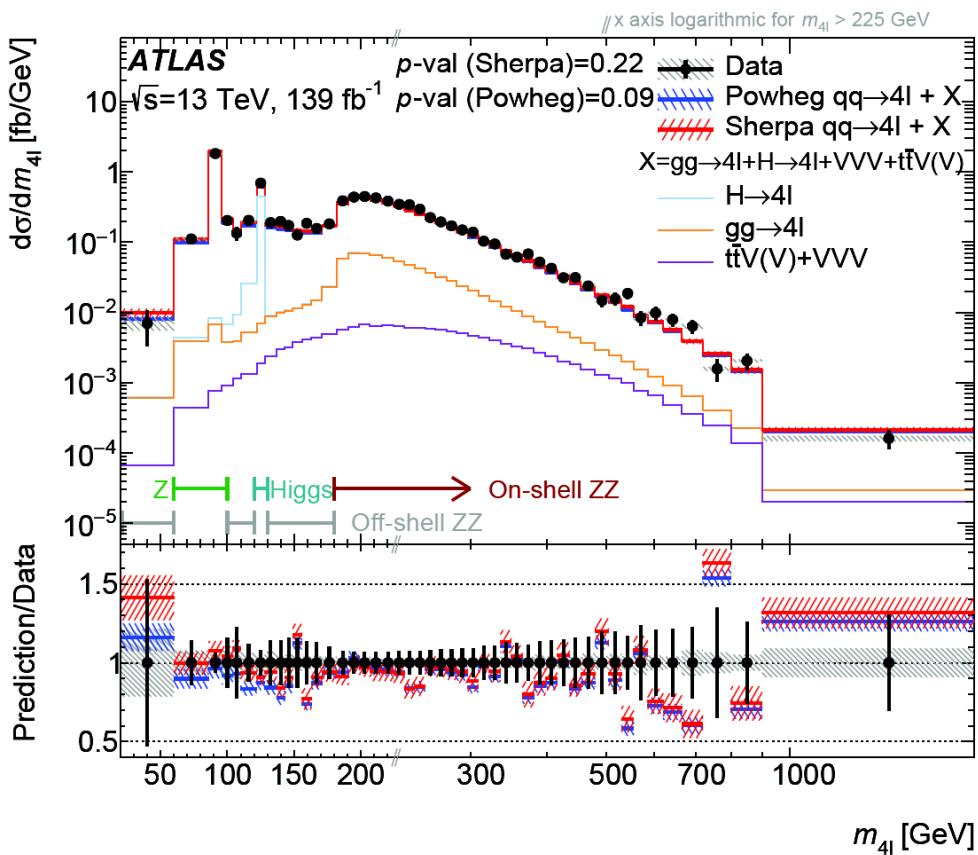
Polarisation in WZ

- First polarisation measurements in dibosons
 - Polarisation of each boson separately
 - Using decay angle of the lepton
- Polarisation fractions are frame-dependent (not Lorentz-invariant)



→ Measurements still dominated by statistical uncertainties

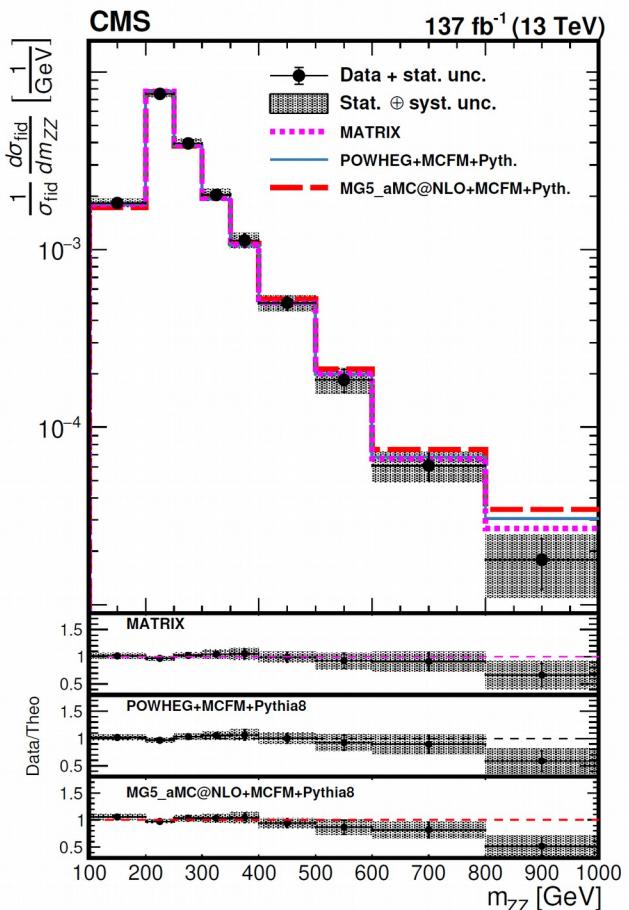
- 4 leptons measurement
- Large kinematic range covered



→ Statistical uncertainty dominates (5 – 30%)

(139 fb^{-1})(137 fb^{-1})

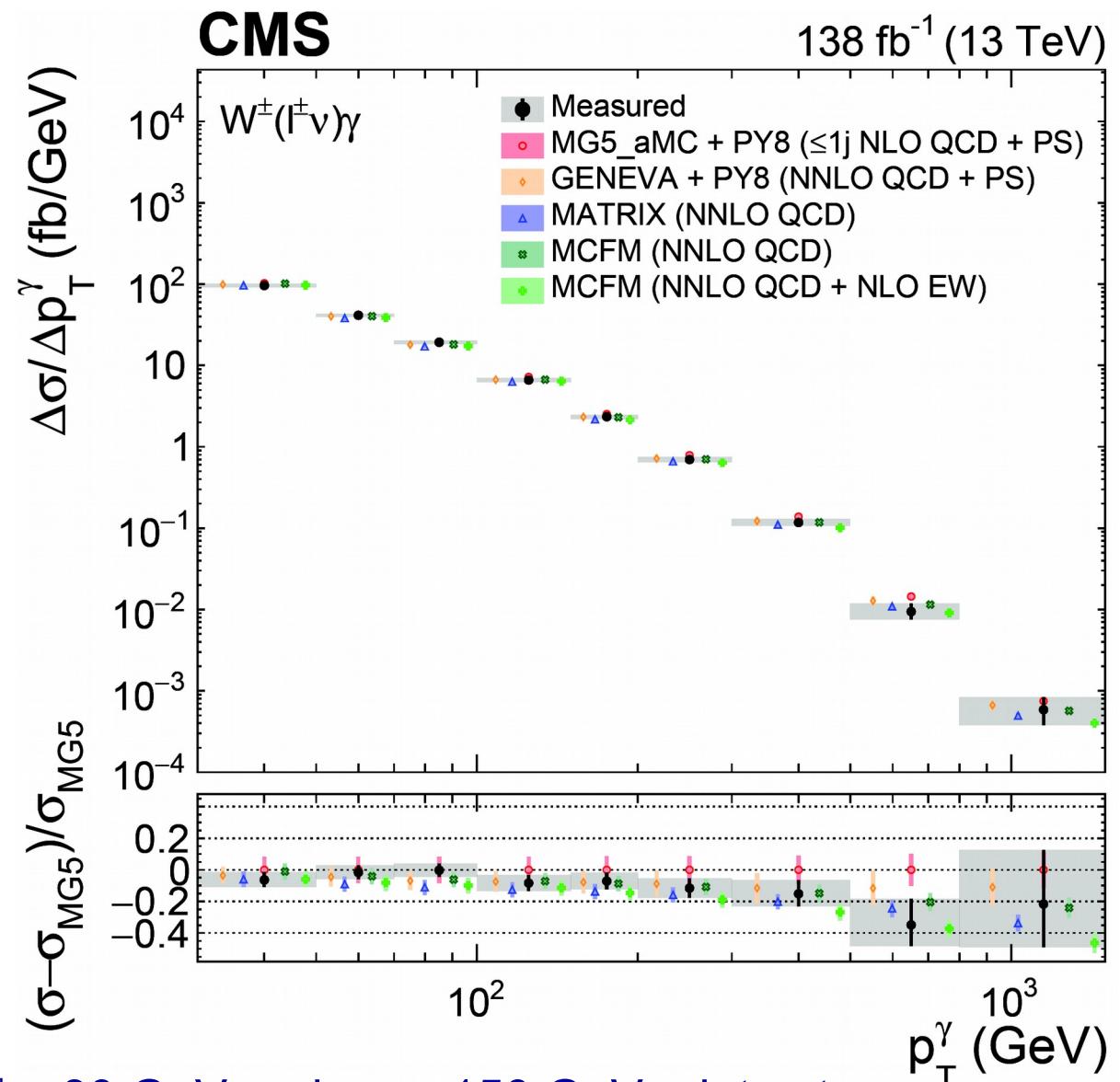
- Compared to MATRIX including EW corrections



- Agreement to MATRIX better
→ Includes EW corrections up to 20-30% at 1TeV

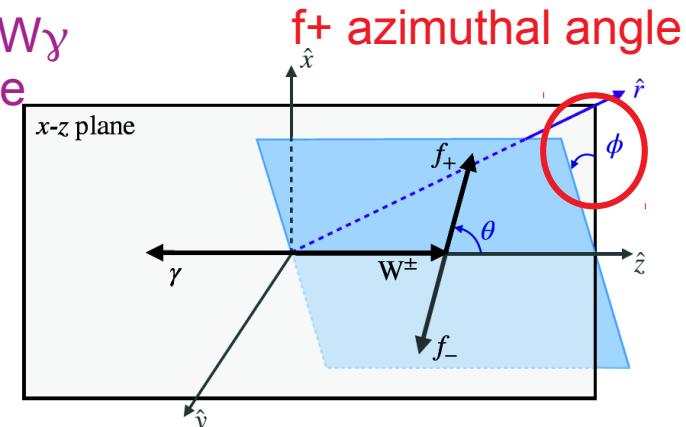
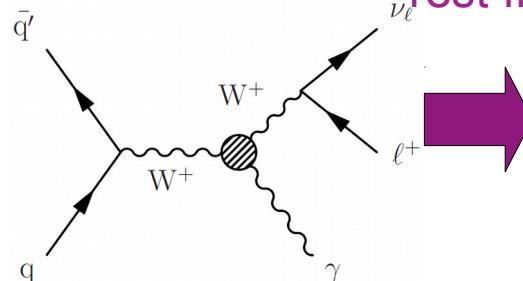


- Inclusive measurement of differential distributions
- 5% precision at low p_T^γ , dominated by experimental systematics
- 40% precision at high p_T^γ : statistical uncertainties
- ➔ Better agreement with NNLO
- ➔ But experimental precision not yet enough to test NLO EW
- Phase space restricted to $p_T^W > 80$ GeV and $p_T^\gamma > 150$ GeV + jet veto for EFT constraints

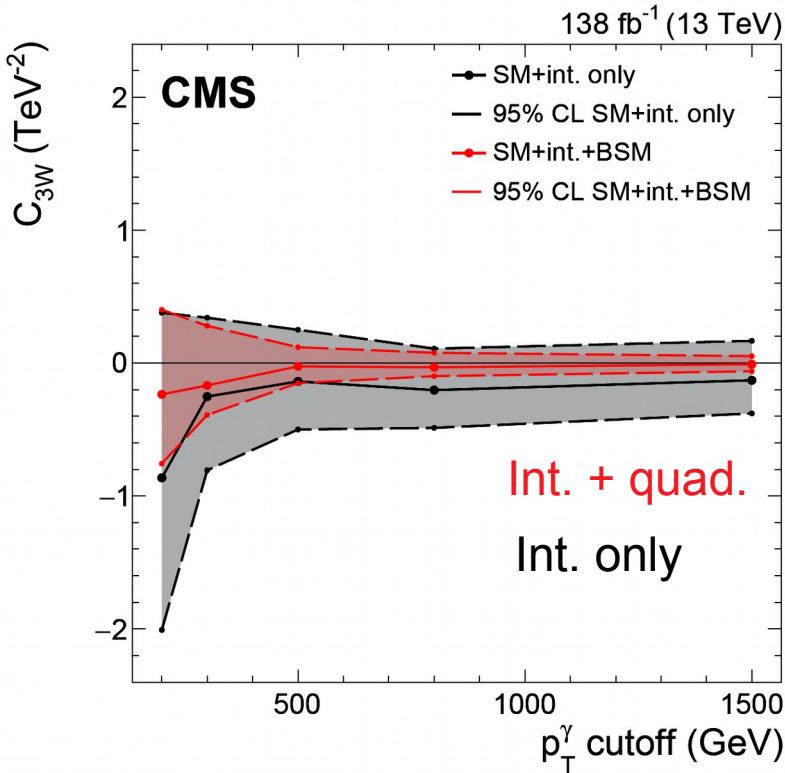




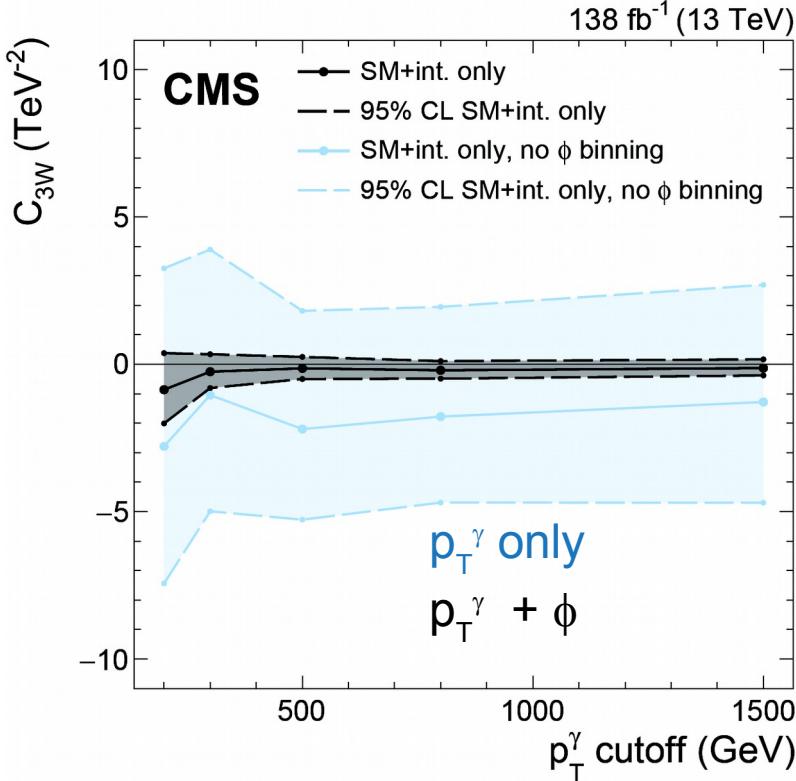
- phi angle to increase SM/BSM interference



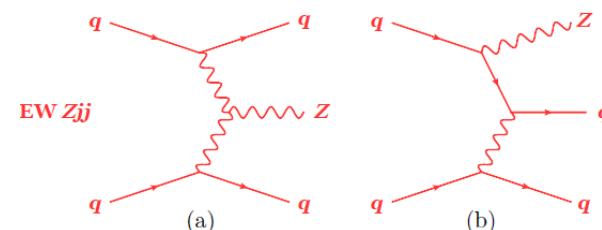
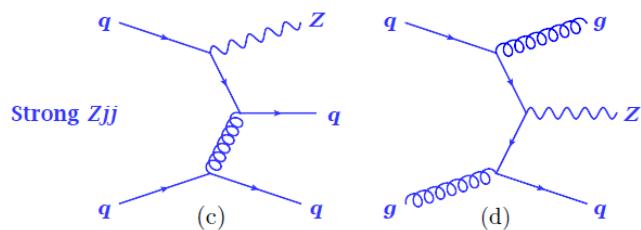
- Interference vs quadratic terms



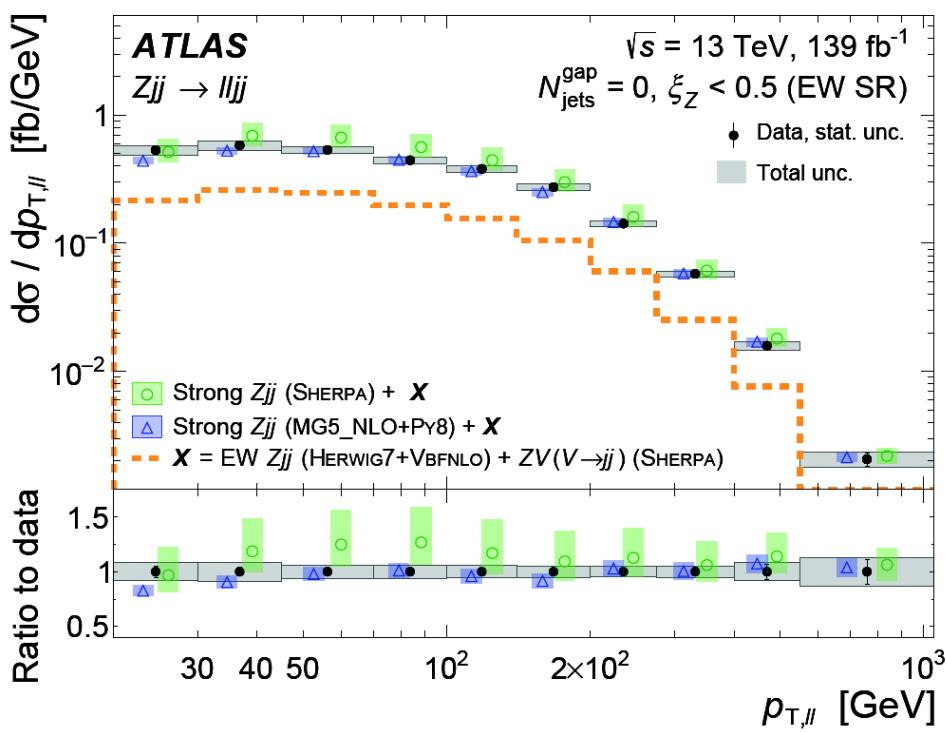
- Resurrection of the interference



► Increased sensitivity to interference

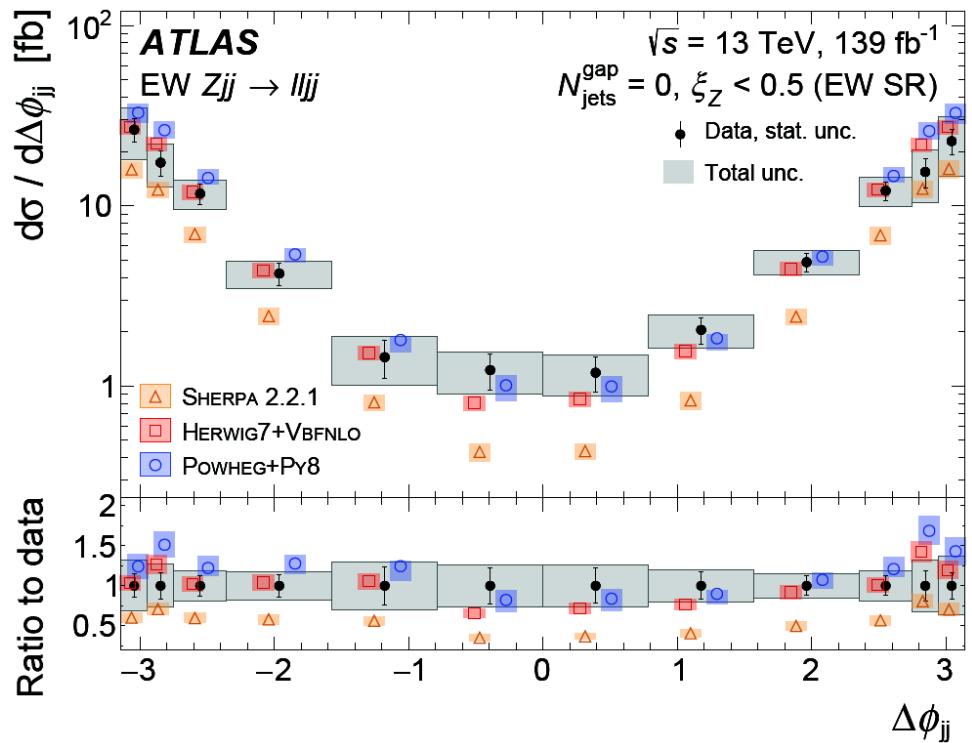


- Differential measurement of QCD+EW Zjj

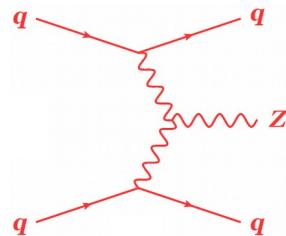


→ Model uncertainty on strong Zjj is dominant

- Differential measurement of EW Zjj



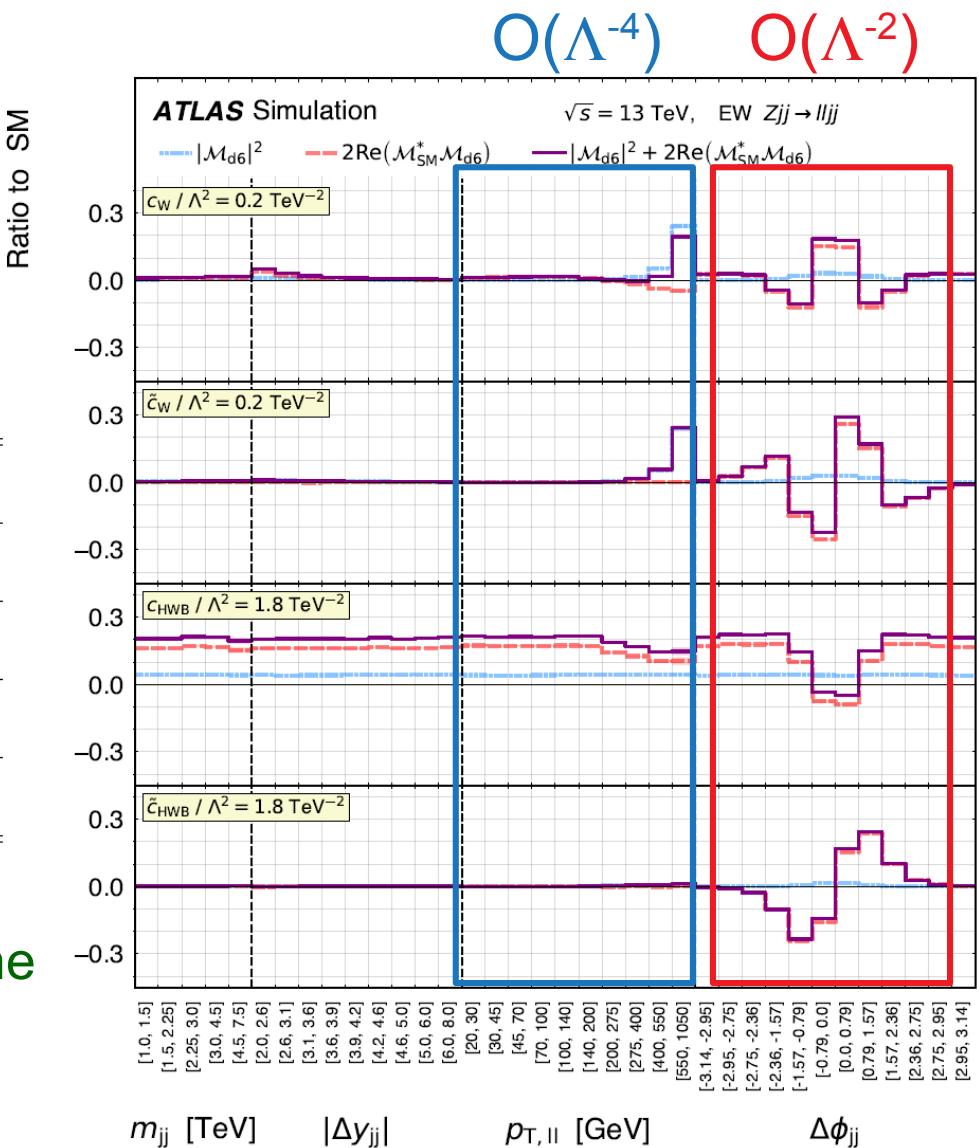
→ Data favour HERWIG7+VBNLO
→ Used for EFT constraints



- Main sensitivity to linear EFT in $\Delta\Phi_{jj}$
- p_T^{\parallel} dominated by $O(\Lambda^{-4})$

Wilson coefficient	Includes $ M_{d6} ^2$	95% confidence interval [TeV $^{-2}$]	p -value (SM)
		Expected	Observed
c_W/Λ^2	no	[-0.30, 0.30]	45.9%
	yes	[-0.31, 0.29]	43.2%
\tilde{c}_W/Λ^2	no	[-0.12, 0.12]	82.0%
	yes	[-0.12, 0.12]	81.8%
c_{HWB}/Λ^2	no	[-2.45, 2.45]	29.0%
	yes	[-3.11, 2.10]	25.0%
$\tilde{c}_{HWB}/\Lambda^2$	no	[-1.06, 1.06]	1.7%
	yes	[-1.06, 1.06]	1.6%

- Best limits for interference terms alone
- Small impact of $O(\Lambda^{-4})$
- Limits on CP-odd Wilson coefficients

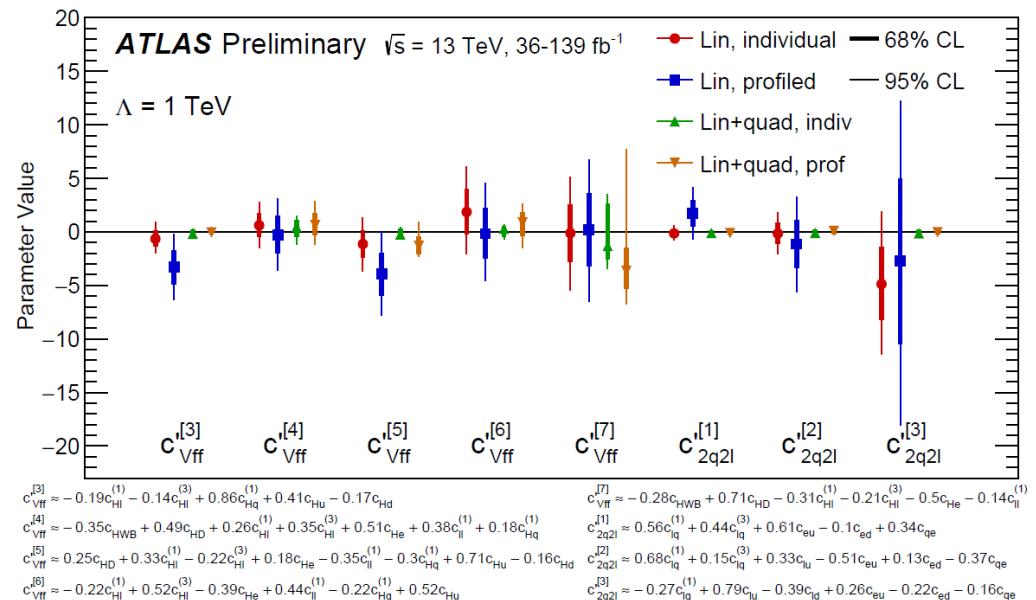
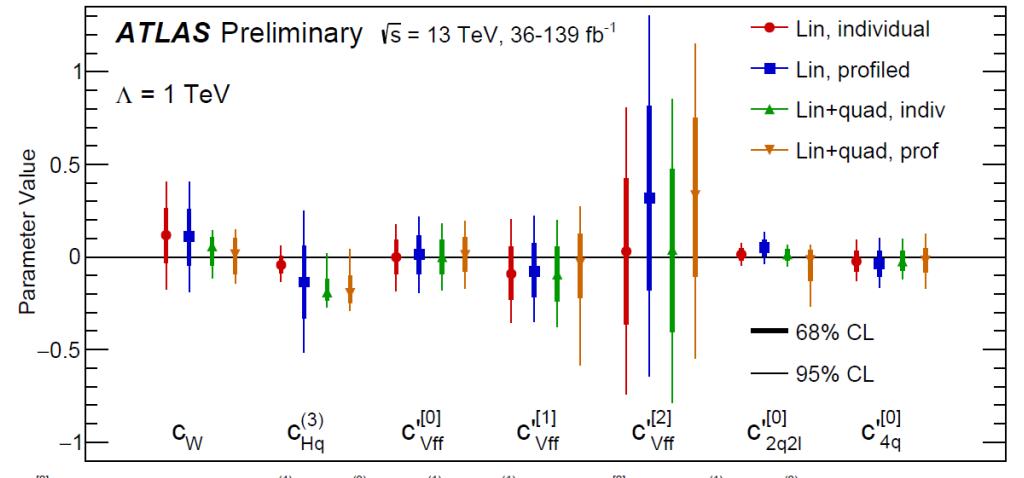


- Combination of WW, WZ, 4l and Zjj measurements
- Based on measured differential cross sections
- Limits on linear combination of reduced set of Wilson coefficient of the Warsaw basis

→ Individual vs. combined sensitivities

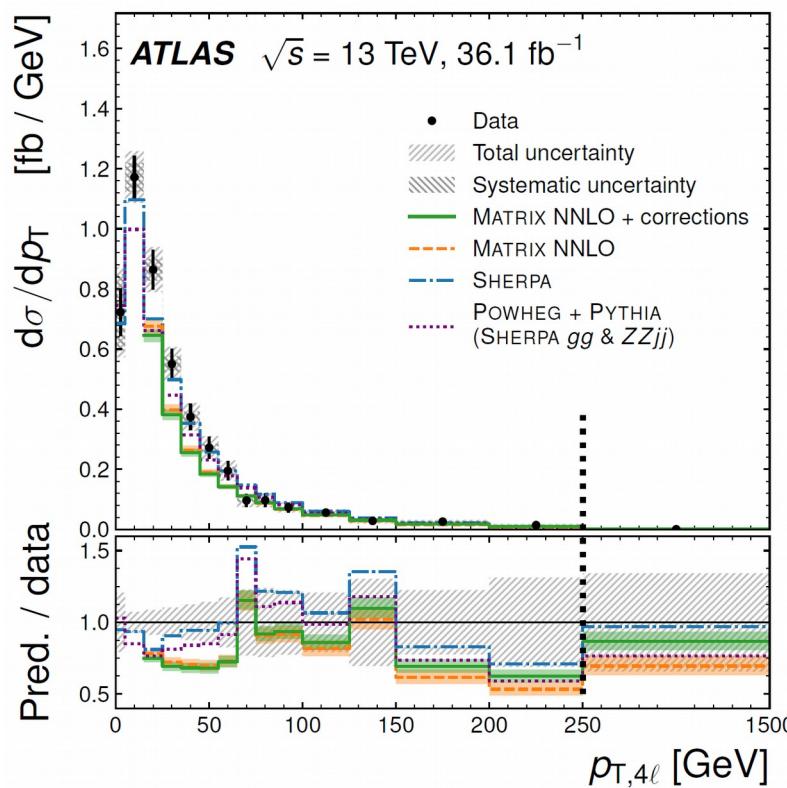
→ Both linear $O(\Lambda^{-2})$ and quadratic $O(\Lambda^{-4})$ contributions investigated

↘ Statistically limited
↘ But theory uncertainties important to probe linear effects



- Differential cross section measurements now challenging theory predictions
 - ➔ Systematic uncertainties are becoming now dominant at low p_T
 - ➔ More time needed for analyses
 - ➔ Interest in having MC generators with higher precision
- Dibosons for EFT constraints
 - ➔ Validity of interpretation without considering dim.8 ?
 - ➔ Angular variables used to improved sensitivity to interference term
 - ➔ Towards global EFT fits, even beyond pure diboson measurements

- Both Z on-shell
- Z decays to e or μ

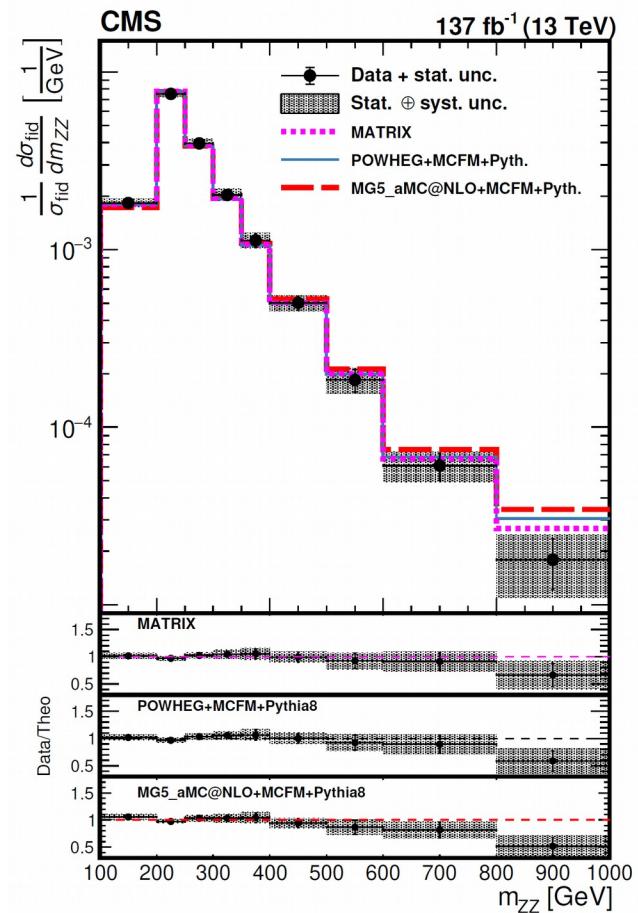


→ Statistical uncertainty dominates (5 – 40%)

(36 fb $^{-1}$)

(137 fb $^{-1}$)

- Compared to MATRIX including EW corrections



- Agreement to MATRIX better
 → Includes EW corrections up to 20-30% at 1TeV