

Multiboson measurements

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(on behalf of the ATLAS & CMS collaborations)



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DER FORSCHUNG | DER LEHRE | DER BILDUNG

Multi(Di)boson productions

- **Gauge boson self couplings predicted in non-abelian $SU(2)\times U(1)$**
→ **Excellent tests of the electroweak sector of SM**
- Sensitive to anomalous gauge couplings → Indirect search for new physics (EFT approach)
- Background for Higgs and new physics searches
- Large cross sections and clean experimental signature
- Precision era for multiboson measurements with LHC run2
- Test theory predictions → New theory developments, improved MC generators, etc.

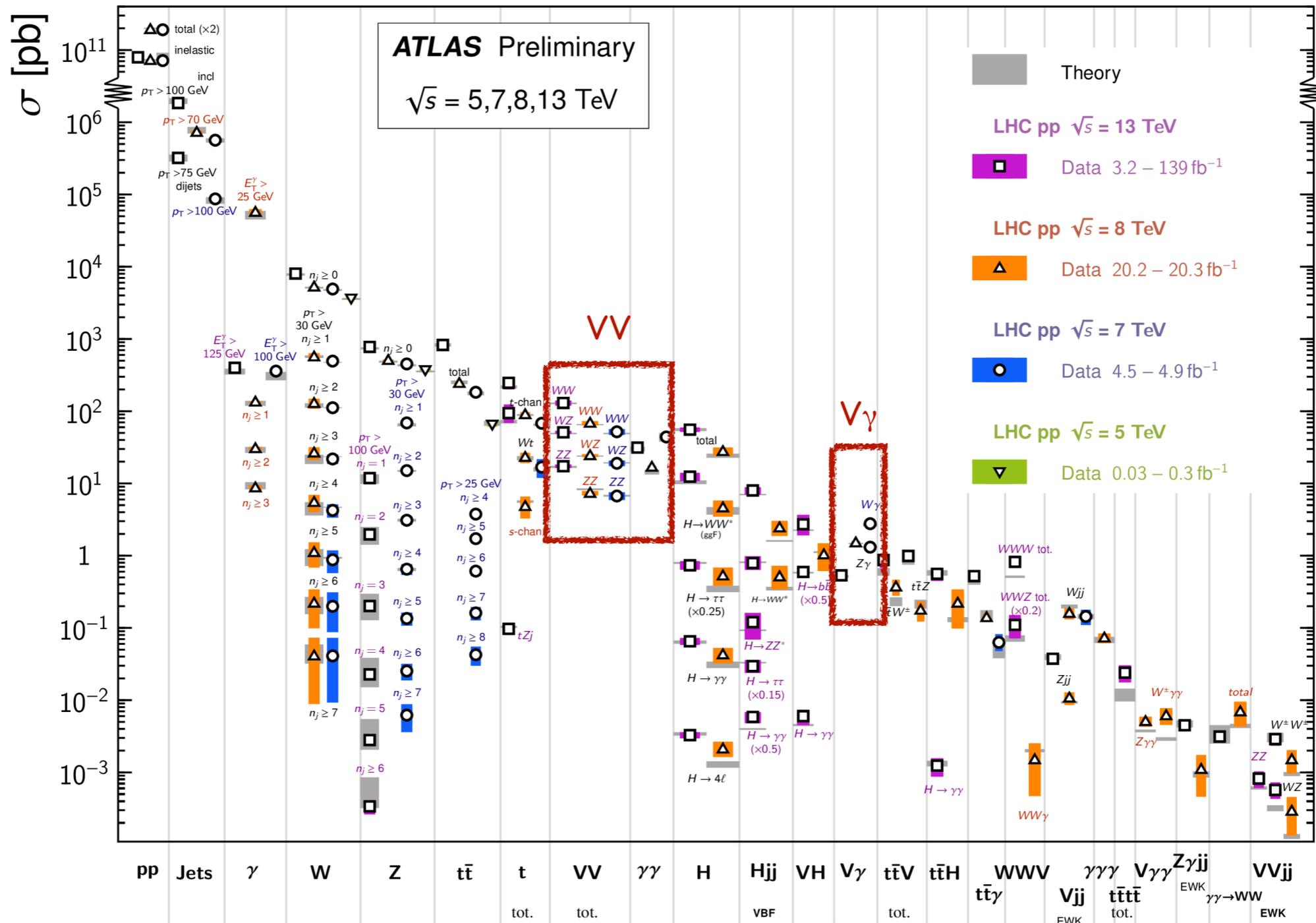
This talk: final states with a pair of $W/Z/\gamma$ with focus on cross section measurements

More on this topic [VVV](#) [VBS](#) [EWK EFT](#) [Diboson](#)
[VBS & VBF](#)

Bird's-eye view



Standard Model Production Cross Section Measurements

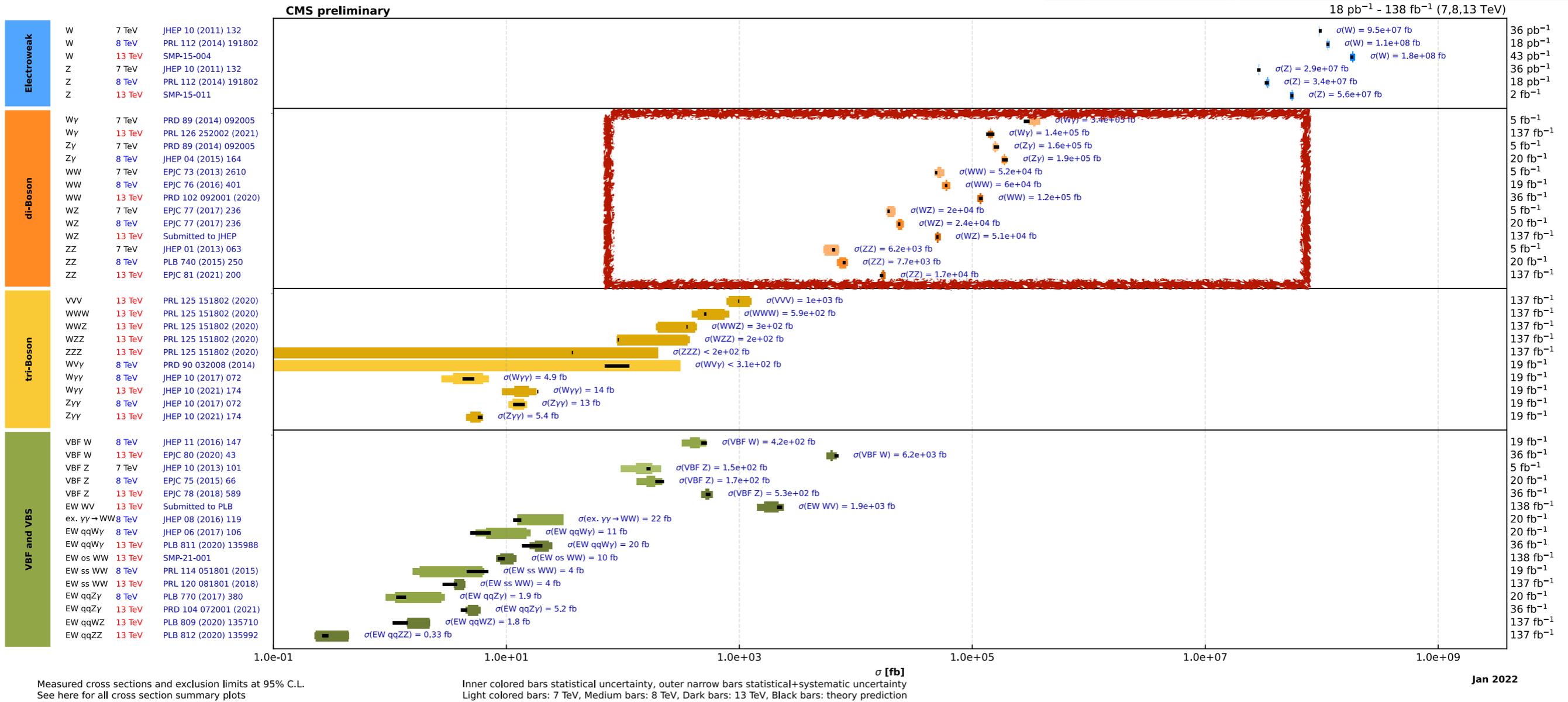


[Link to the plot](#)

Bird's-eye view



Overview of CMS cross section results

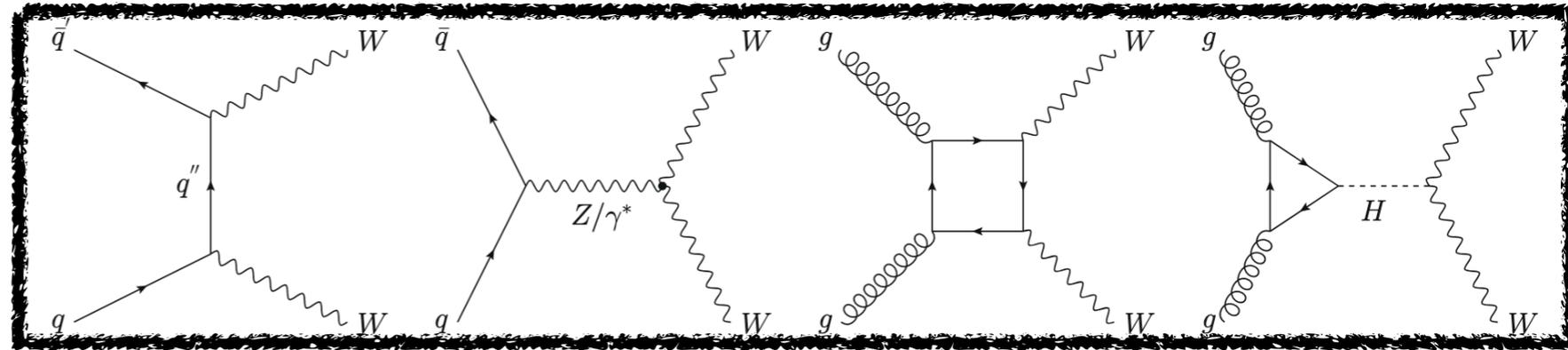


[Link to the plot](#)

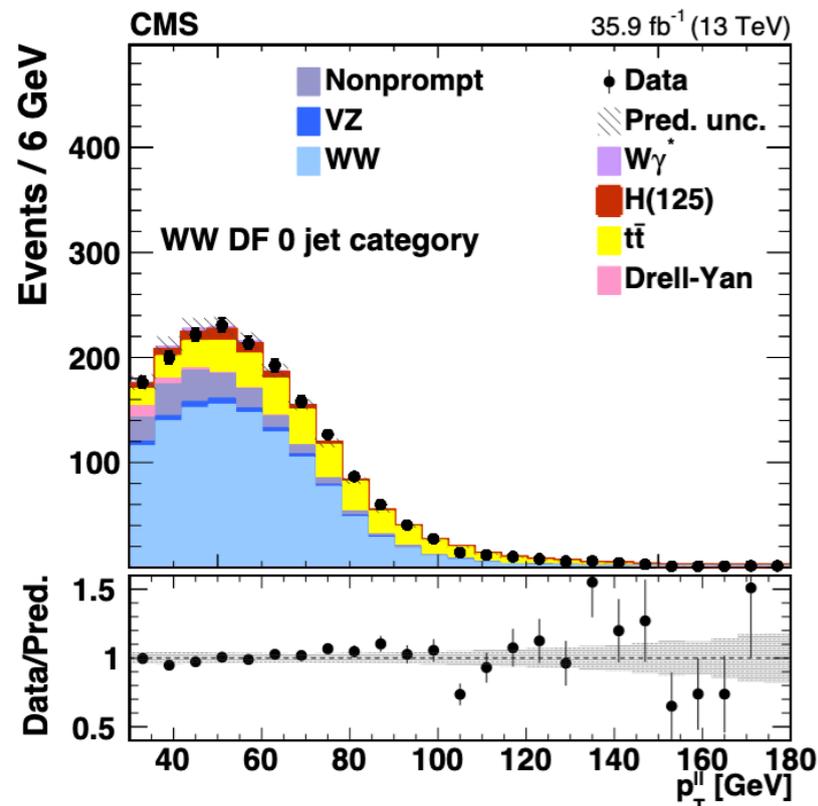


qqbar annihilation + gluon-gluon fusion (resonant & non-resonant) induced

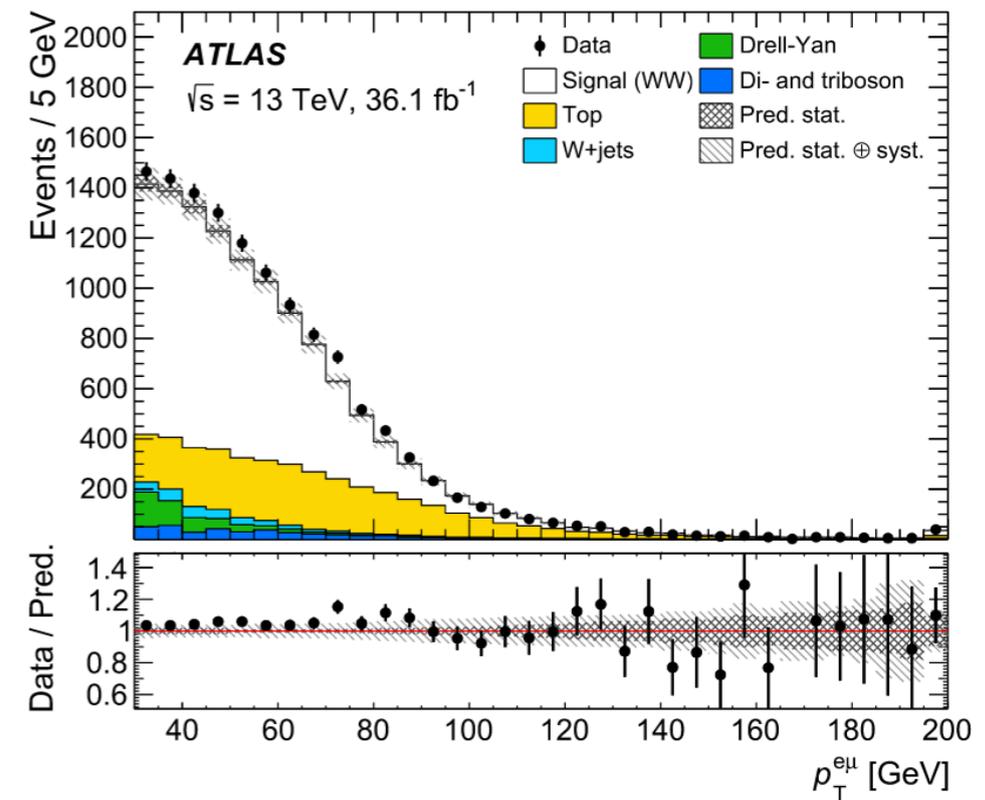
- Fiducial & differential cross sections
- Search for anomalous gauge couplings



- Dominant top quark background with relatively smaller contributions from DY, non-prompt leptons and diboson productions

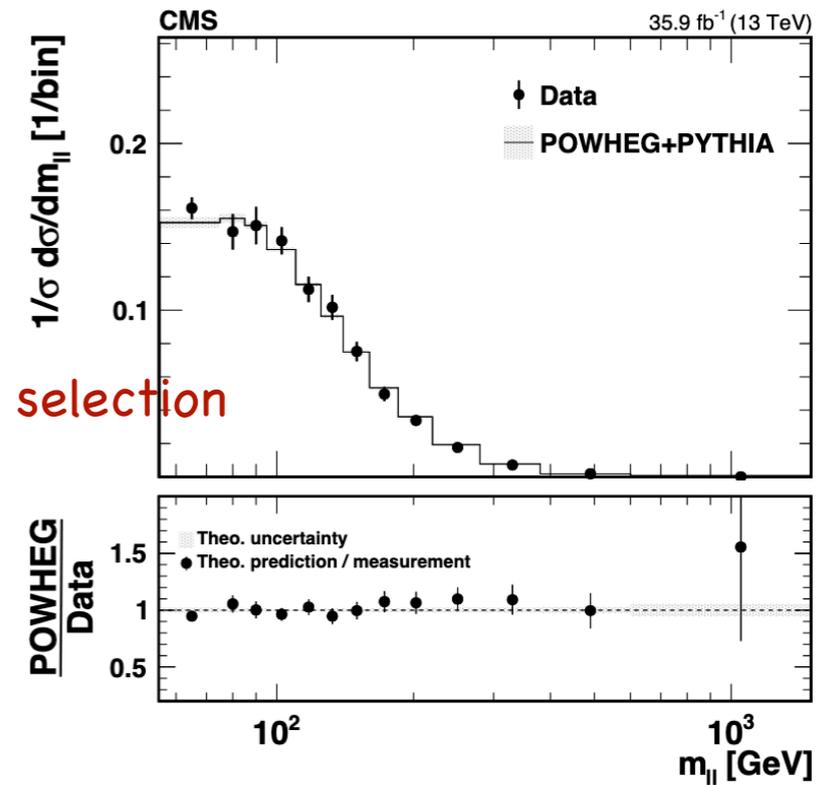
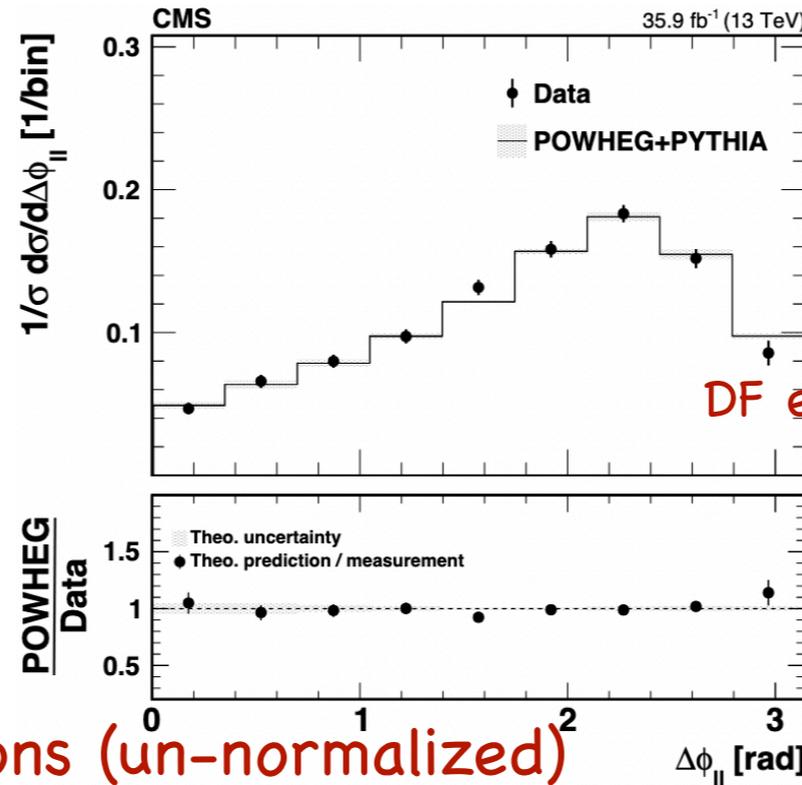


36 fbinv of data
CMS: WW → ll+met;
 0/1 jets & inclusive
ATLAS: WW → eμ+met;
 0 jet

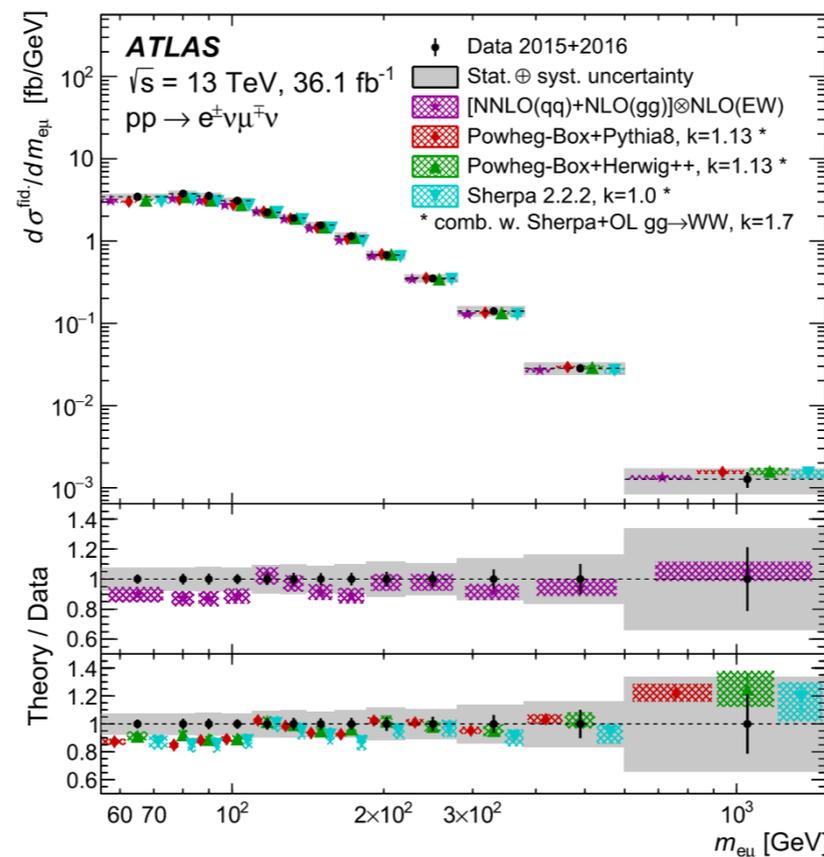
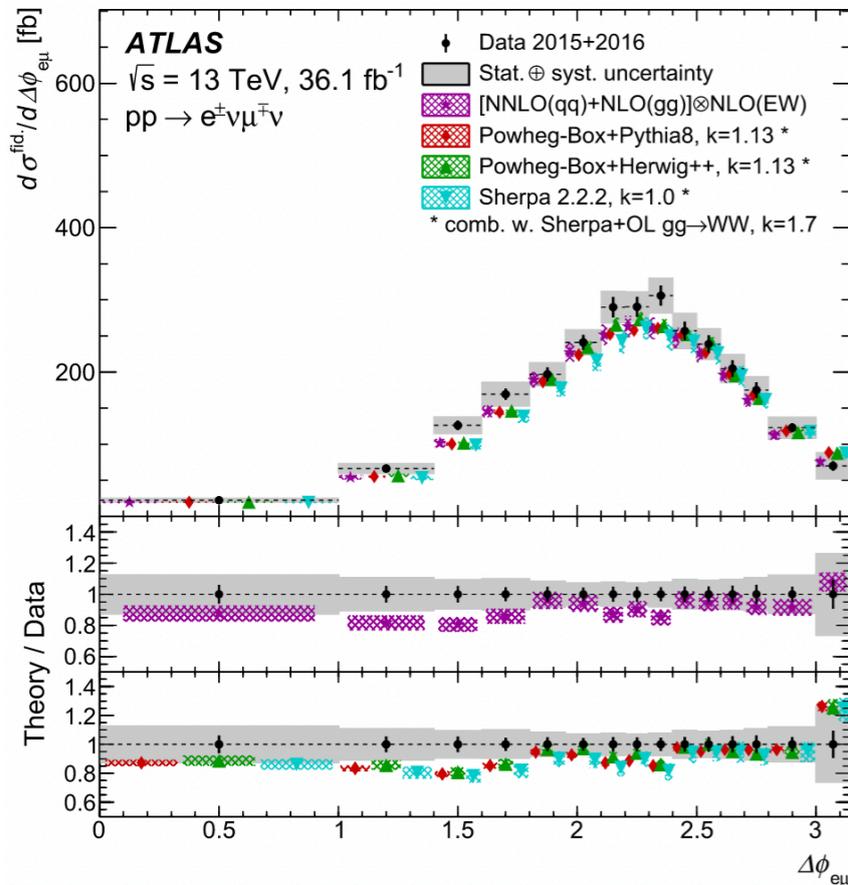


Good agreement between data & NLO theoretical predications

Normalised differential cross sections



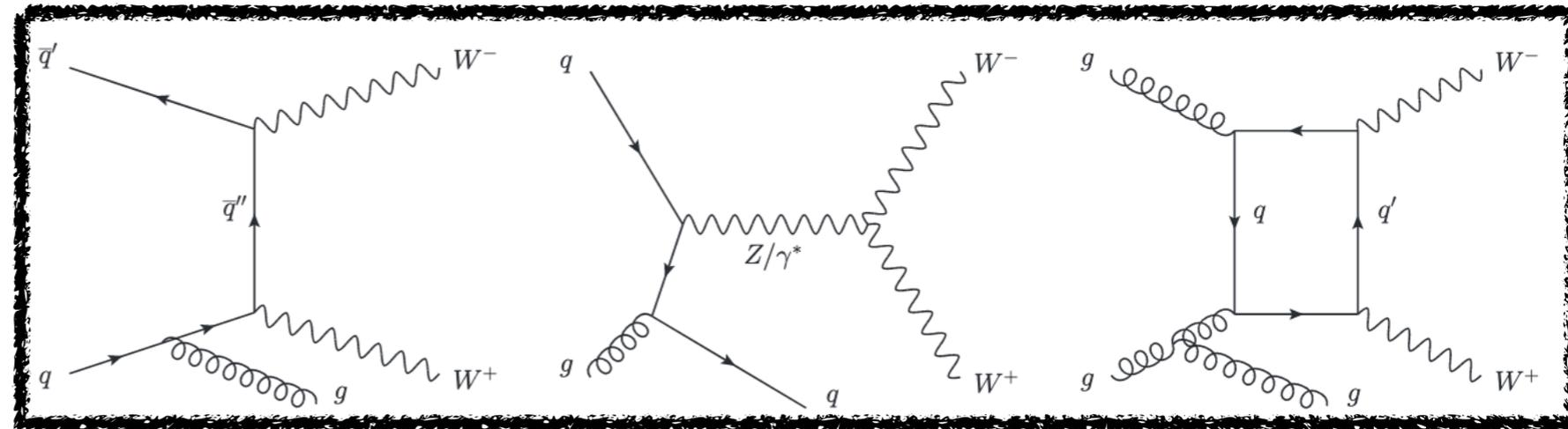
Differential cross sections (un-normalized)



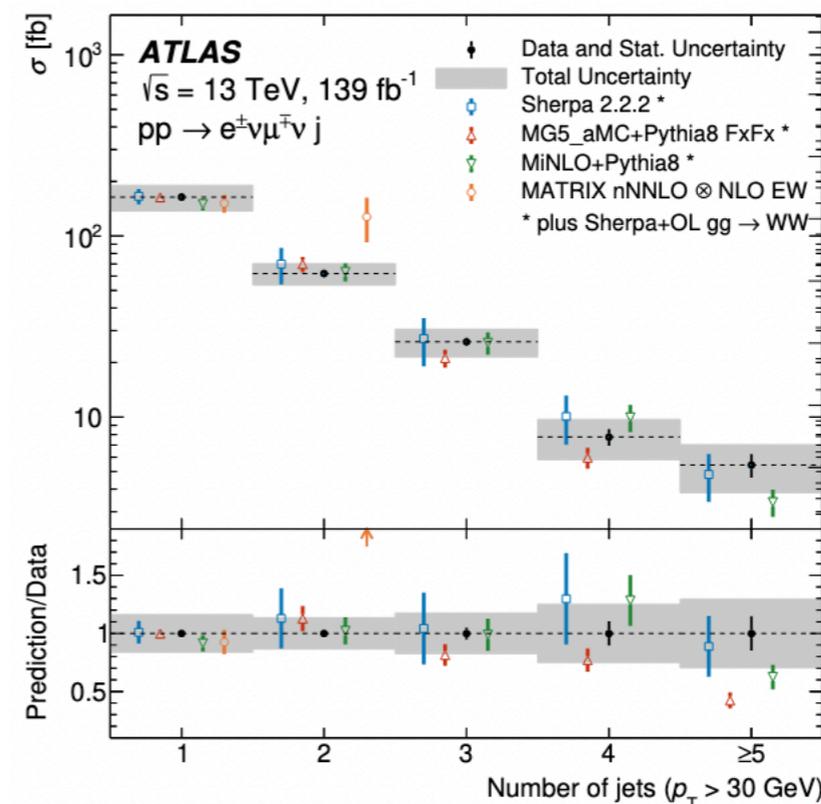
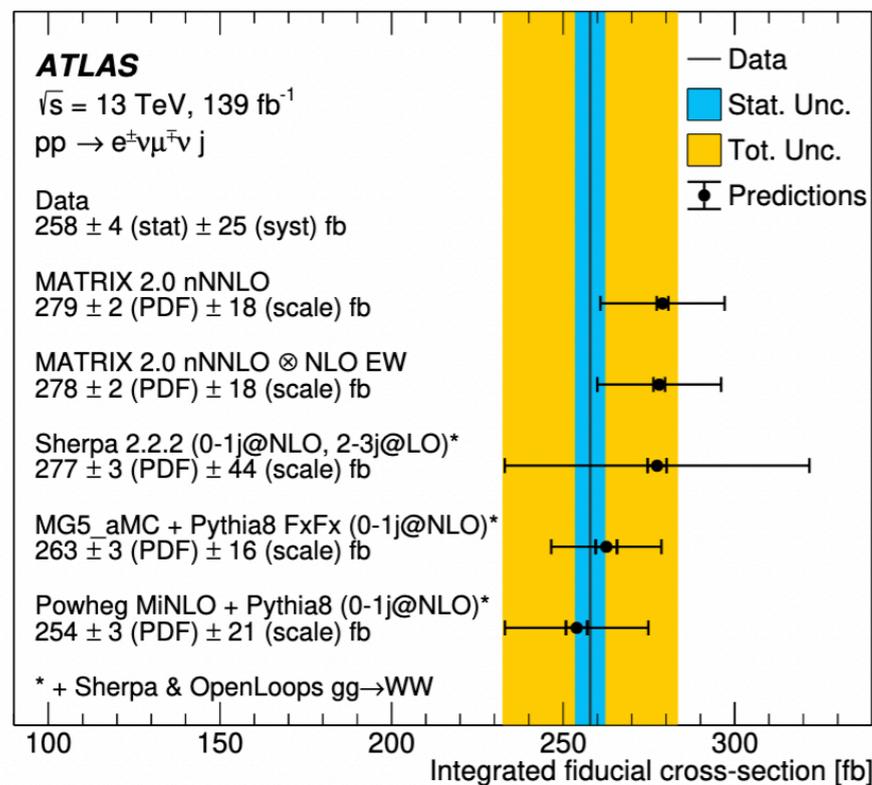
Predictions provide a fair description of data expect for low values of dφ & m_{ll}

WW+≥1jet

- Electron-muon final state with at least one jet with 139 fbinv



- Differential cross-sections as a function of lepton & jet-related observables
- Limits set on anomalous triple gauge couplings → Enhanced interference between SM and anomalous amplitudes with hard jet requirement

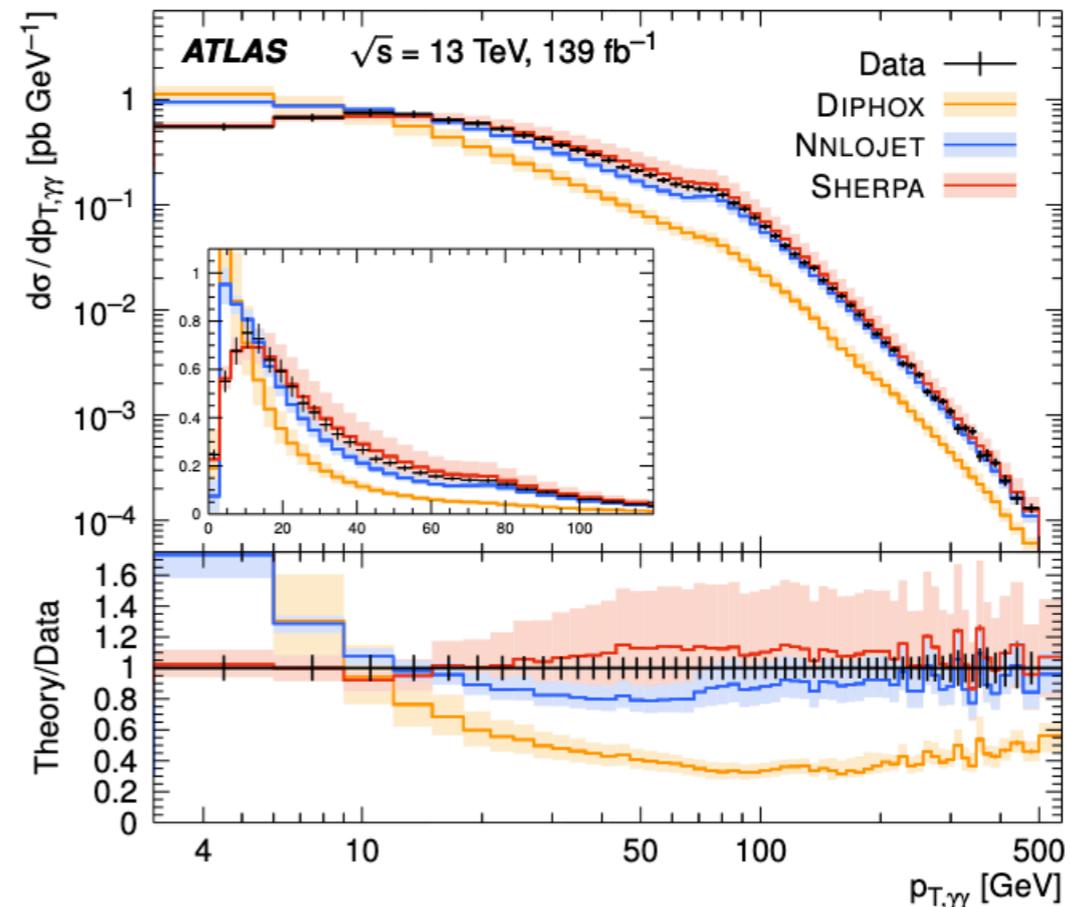
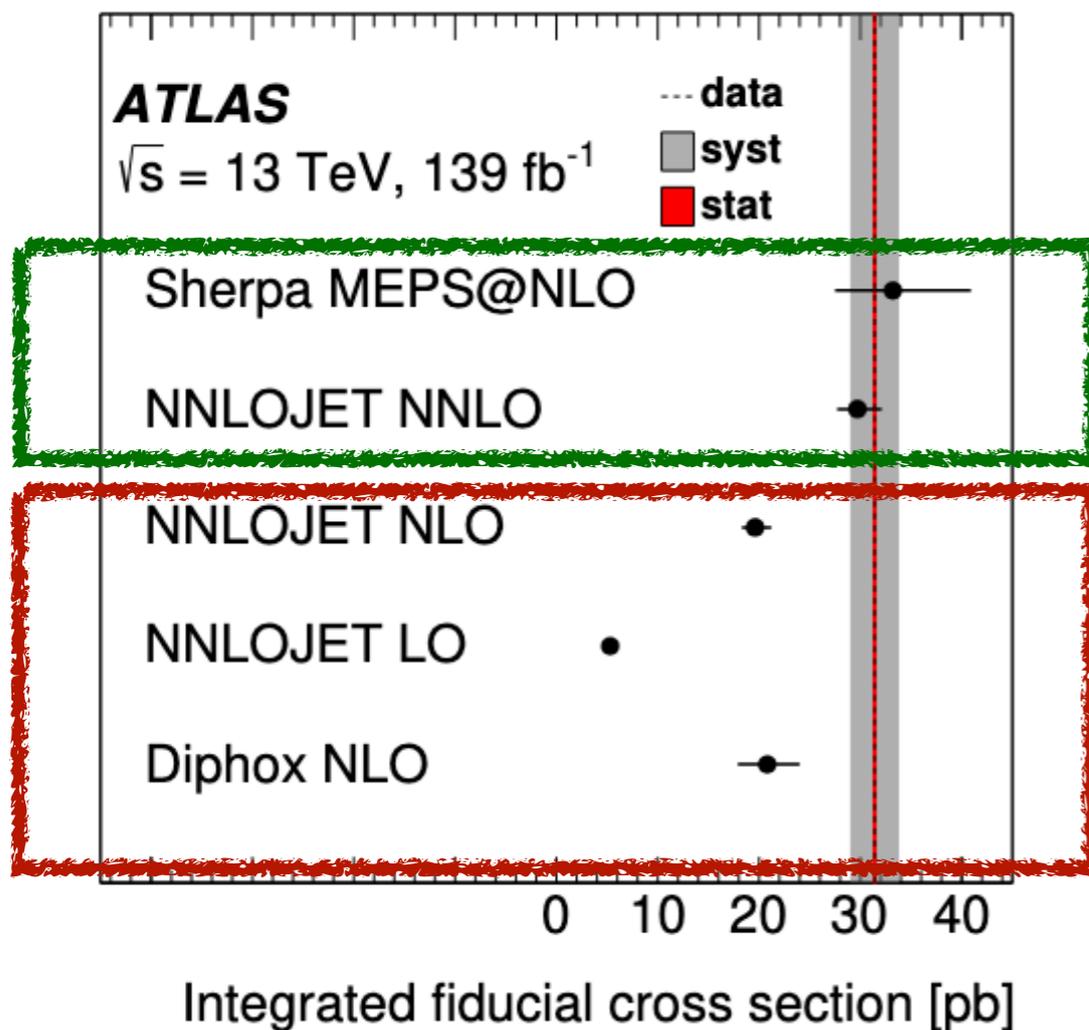
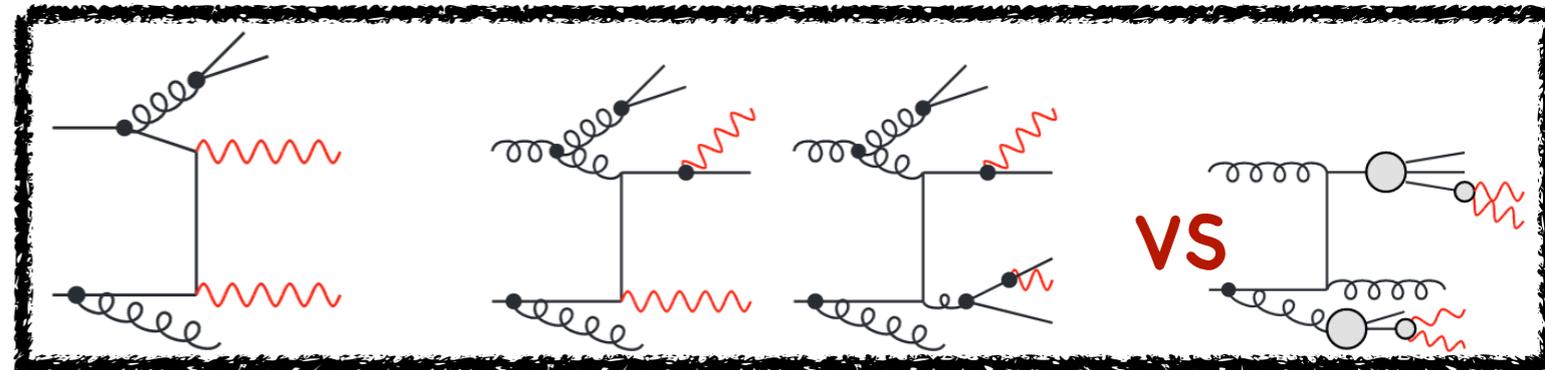


Within uncertainties, all predictions give an excellent description of data

YY

- Electromagnetic process yet involves intricate strong interactions dynamics
 → Non-trivial theoretical predictions

- Differential cross sections as functions of several observables for the $\gamma\gamma$ system based on 139 fb $^{-1}$



SHERPA & NNLOJET → Fair description

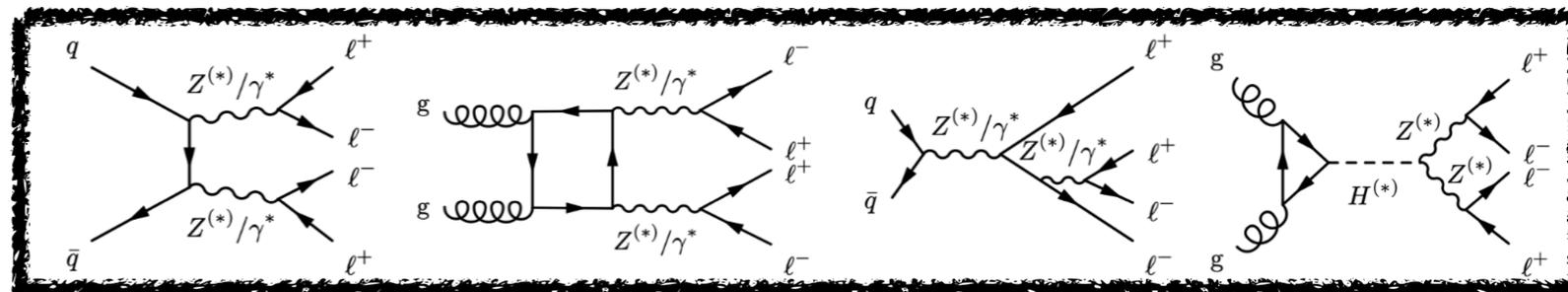
Higher order theoretical cross sections are needed to obtain good shape & normalization agreement with data



Four leptons

Inclusive four lepton production based on 139 fb⁻¹

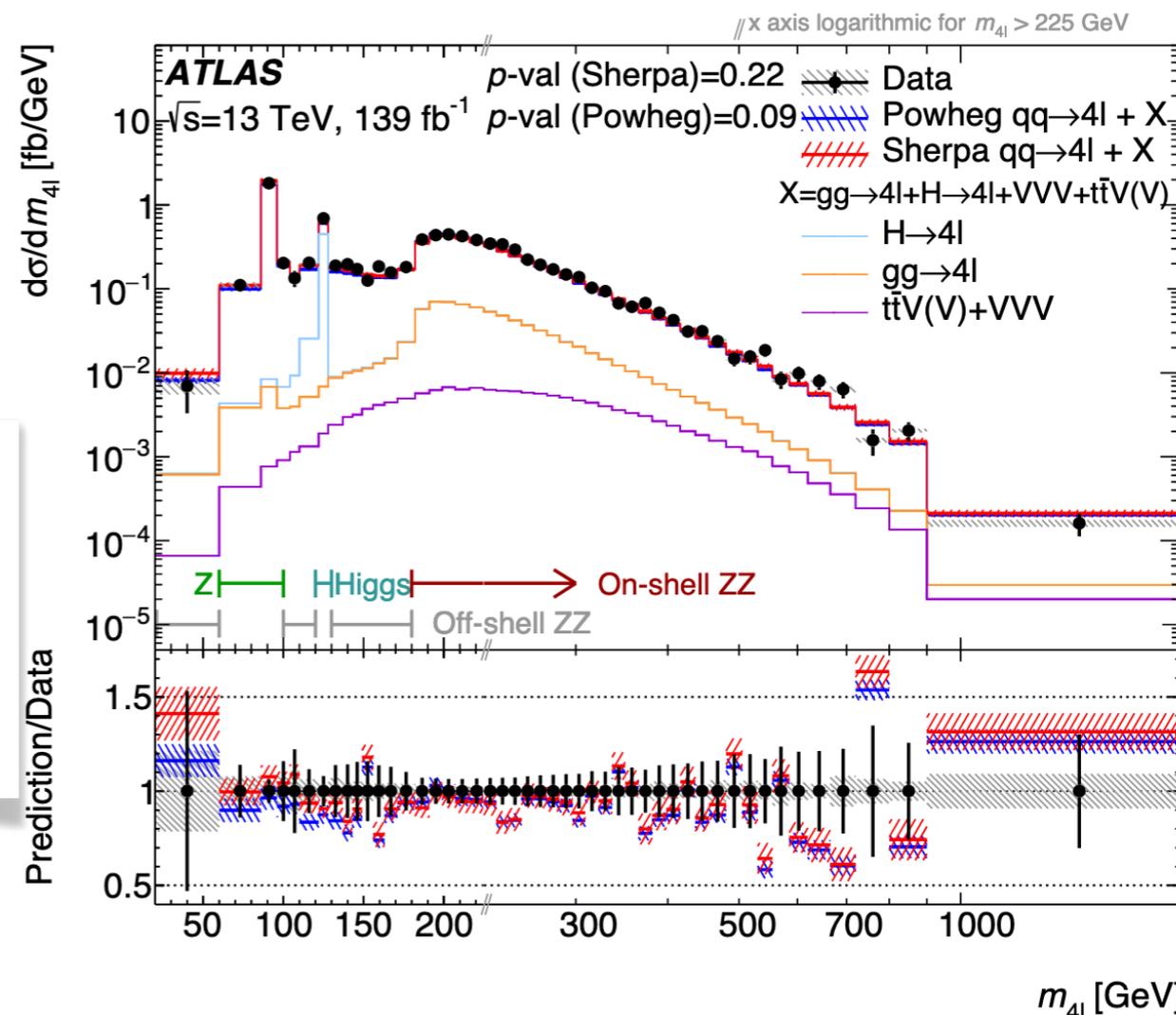
- Differential measurements in four regions
- On-shell ZZ
- Off-shell ZZ
- Single Z boson
- Higgs



Applied k-factor corresponding to NNLO prediction (MATRIX)

	Full	Z → 4ℓ	Region H → 4ℓ	Off-shell ZZ	On-shell ZZ
Measured fiducial cross-section [fb]	88.9	22.1	4.76	12.4	49.3
	±1.1 (stat.)	±0.7 (stat.)	±0.29 (stat.)	±0.5 (stat.)	±0.8 (stat.)
	±2.3 (syst.)	±1.1 (syst.)	±0.18 (syst.)	±0.6 (syst.)	±0.8 (syst.)
	±1.5 (lumi.)	±0.4 (lumi.)	±0.08 (lumi.)	±0.2 (lumi.)	±0.8 (lumi.)
	±3.0 (total)	±1.3 (total)	±0.35 (total)	±0.8 (total)	±1.3 (total)
SHERPA	86±5	23.6±1.5	4.57±0.21	11.5±0.7	46.0±2.9
POWHEG + PYTHIA8	83±5	21.2±1.3	4.38±0.20	10.7±0.7	46.4±3.0

central values comparable here

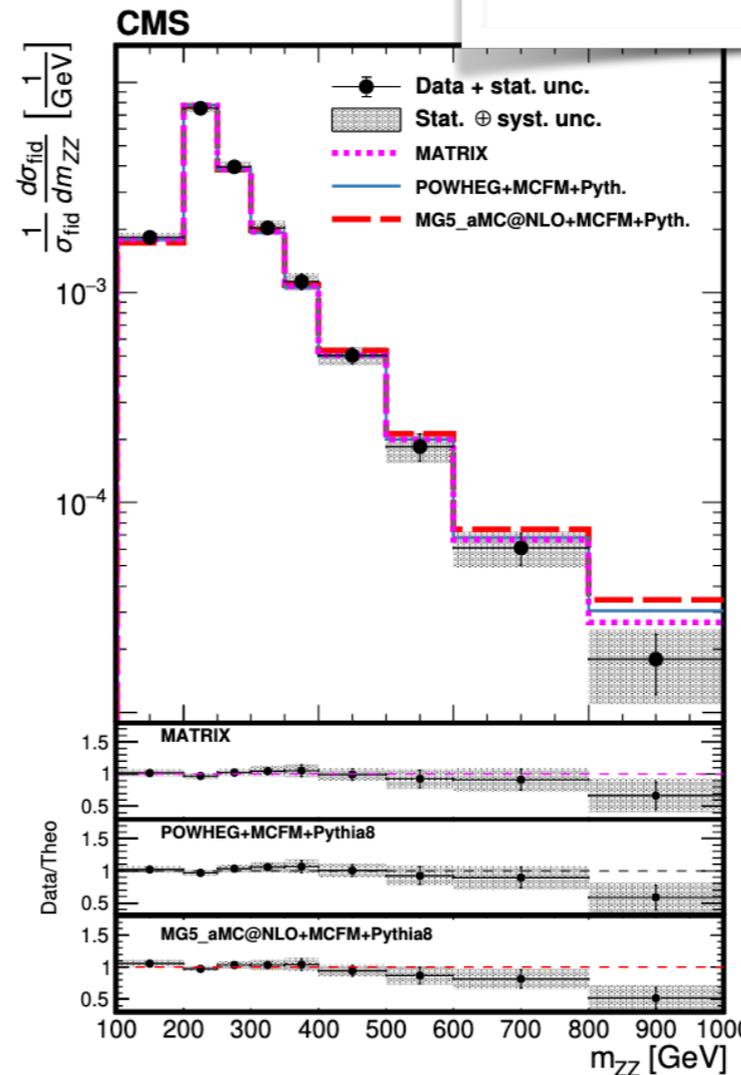
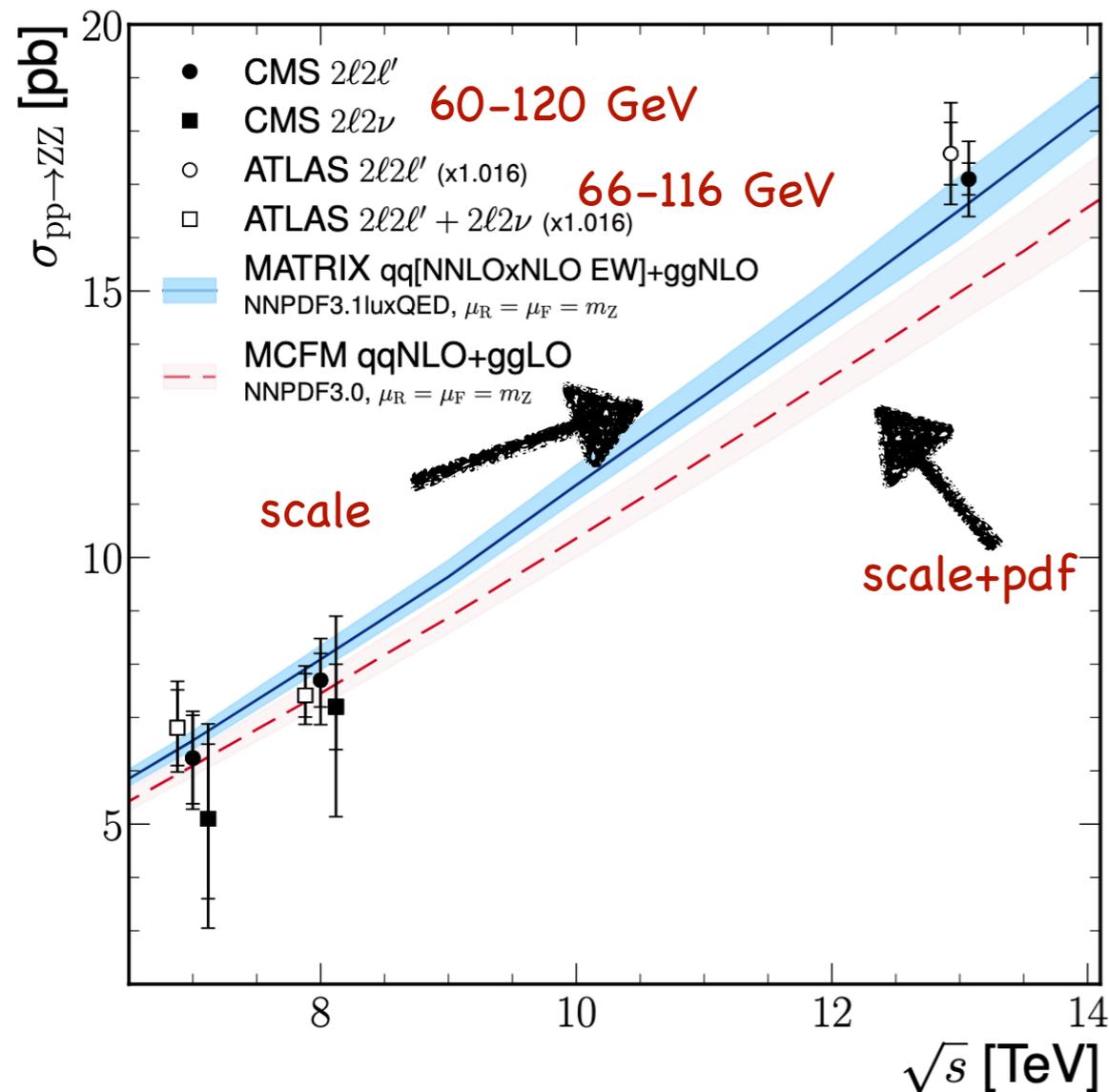
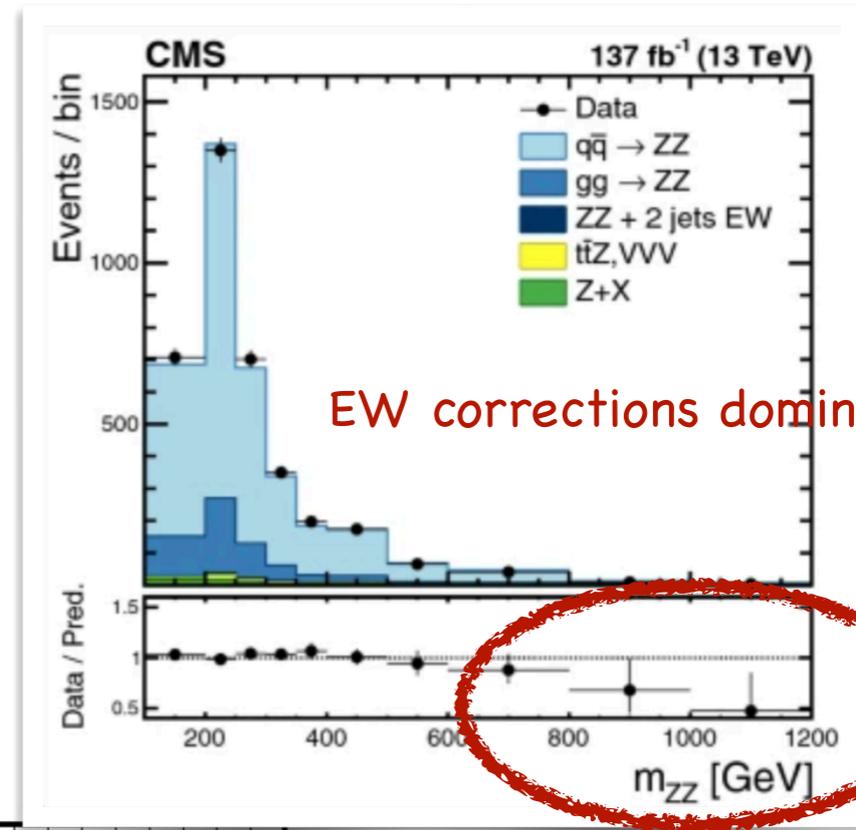


Data and predictions agree within uncertainties



ZZ

- Fiducial & differential cross section measurements **with on-shell ZZ**
- Includes interference with off-shell Higgs production
- Also includes EW ZZ production ~1% of the total signal contribution

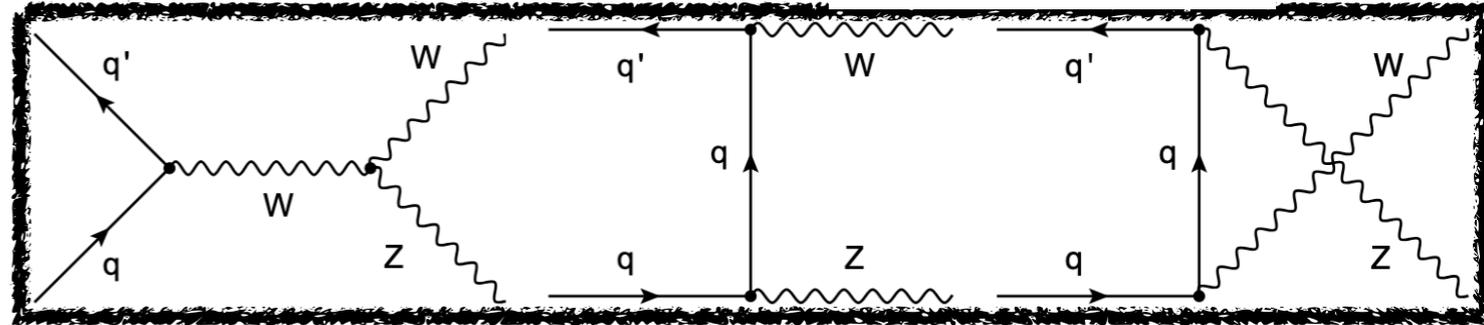


POWHEG+MCFM & MADGRAPH5 aMC@NLO+MCFM describe data well except for the last bin as expected

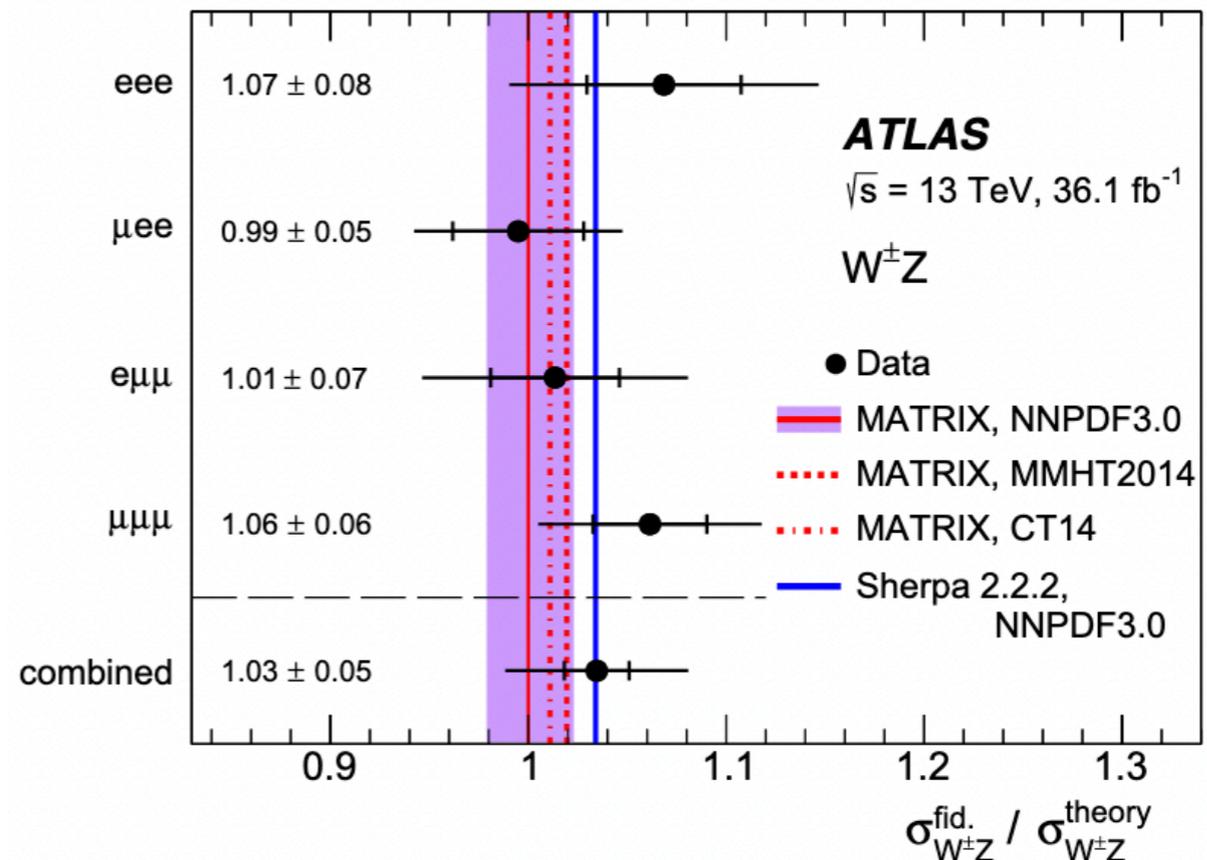
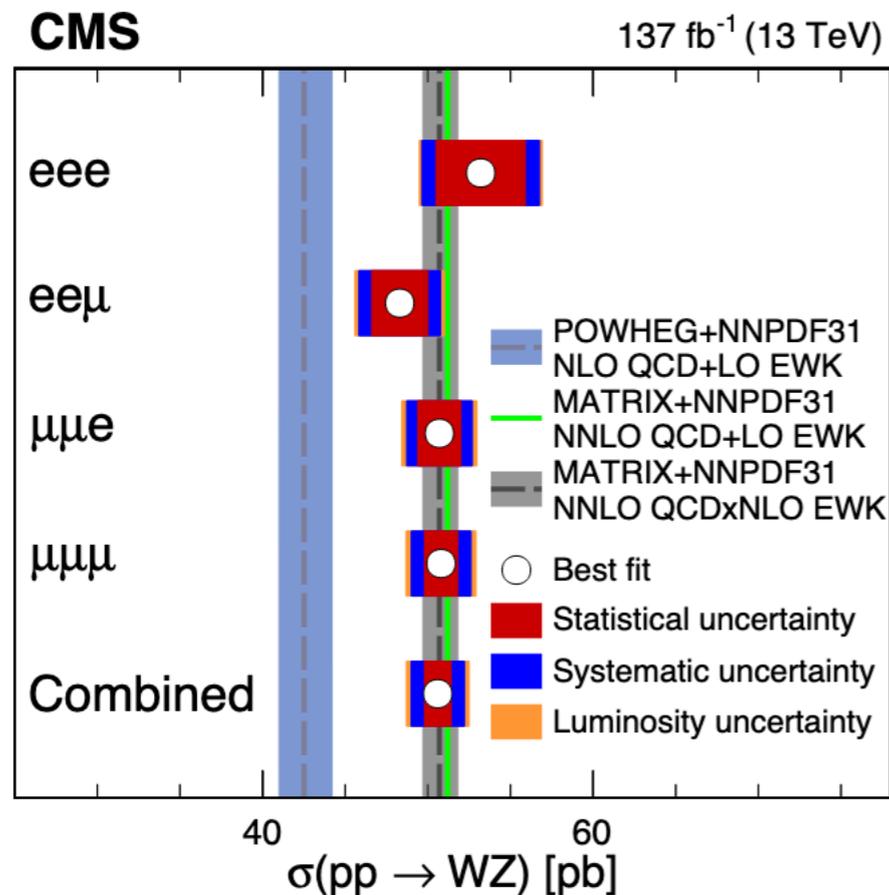


WZ \rightarrow 3lv channel

- ATLAS: 36 fbinv
- CMS: 138 fbinv
- Comprehensive study of WZ \rightarrow 3lv
 - Fiducial & differential cross-sections
 - Charge asymmetry ratio
 - Search for anomalous gauge couplings in the EFT (not covered in this talk!)
 - Boson polarization fraction studies (not covered in this talk!)



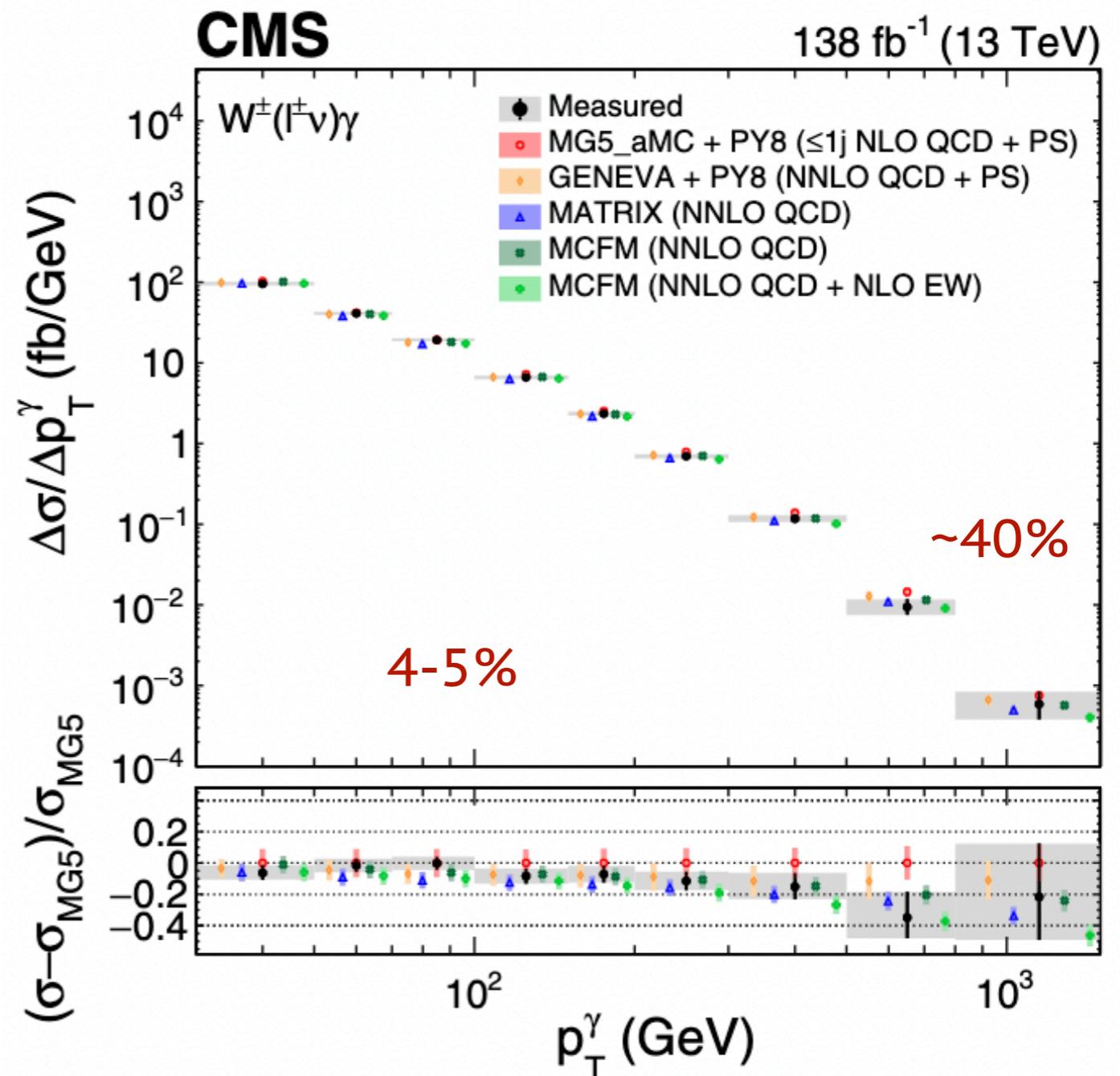
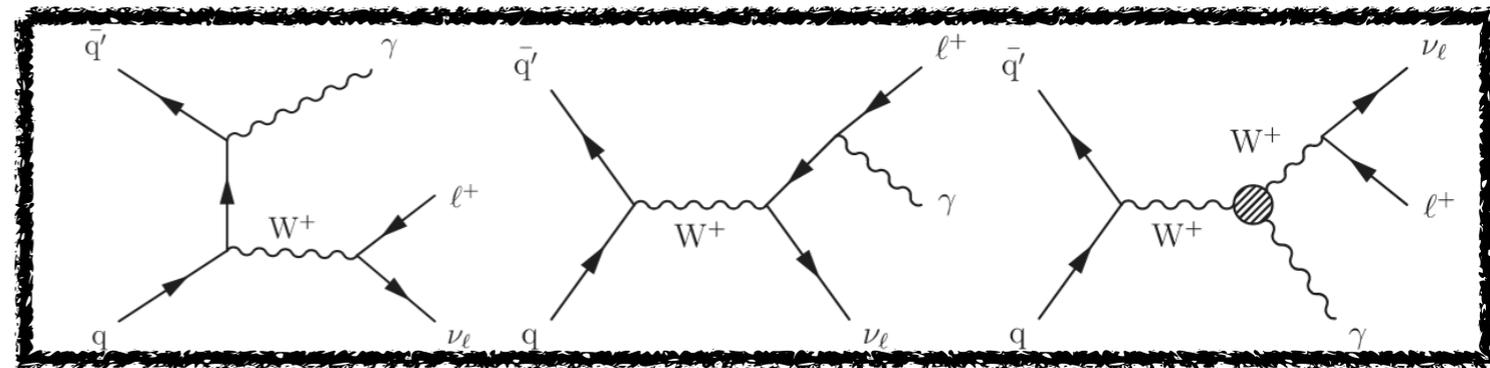
Data favor NNLO prediction





W γ

- Differential cross sections measured for many observables based on 138 fb⁻¹
- Decay of W into either a muon or an electron
- Measurement of photon p_T & angular properties of final state particles exploited to set constraints on aTGC
- Interference resurrection
- Sensitivity to SM-dim6 interference enhanced ~ by a factor of 10



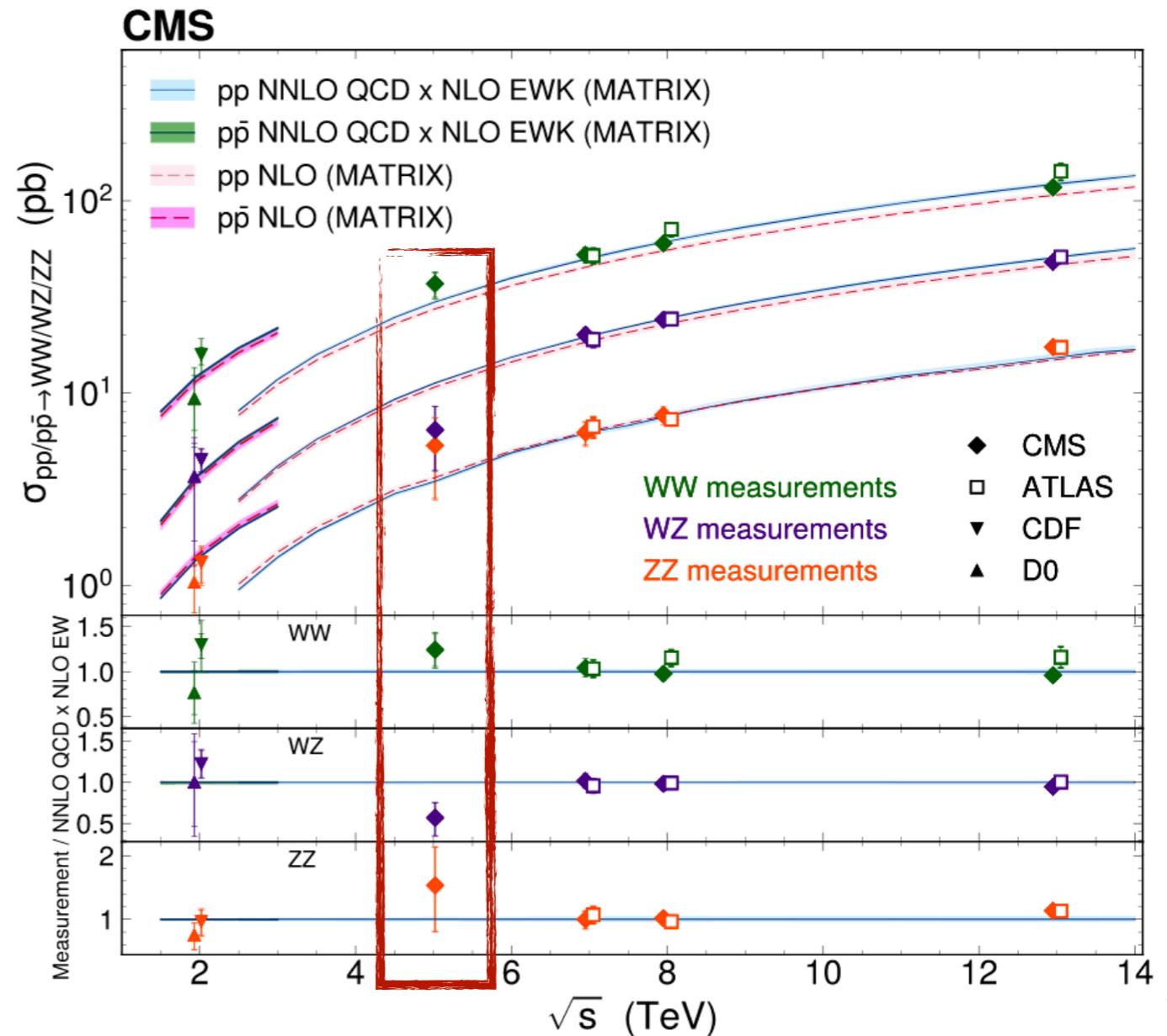


Diboson cross section measurements at 5.02 TeV

- First measurement of the diboson: WW, WZ($\rightarrow 3lv, 2\mu ss$), and ZZ($\rightarrow 4l, 2l2\nu$) production cross sections with **304 pbinv of low pileup data @5.02 TeV**
- Energy point closer to Tevatron measurements from LHC side

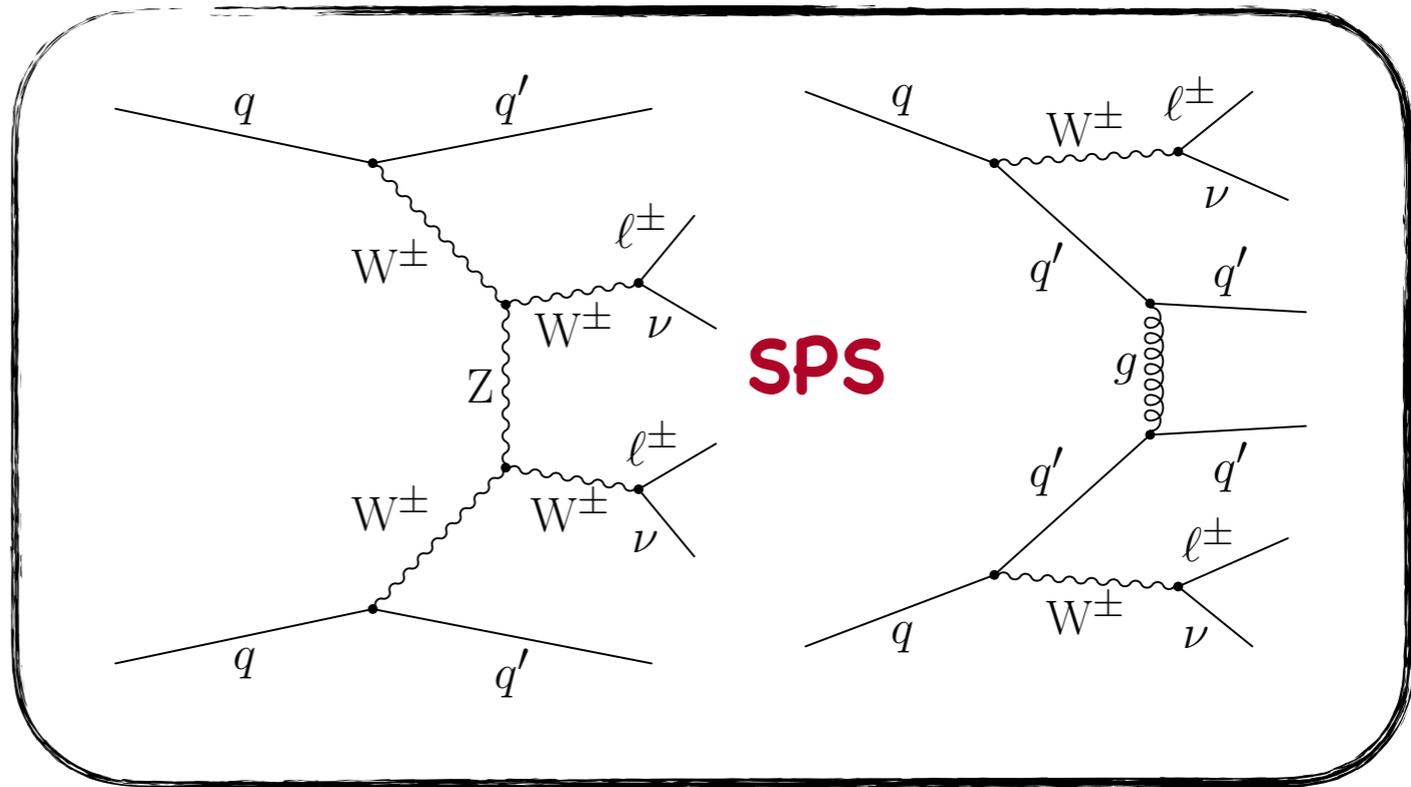
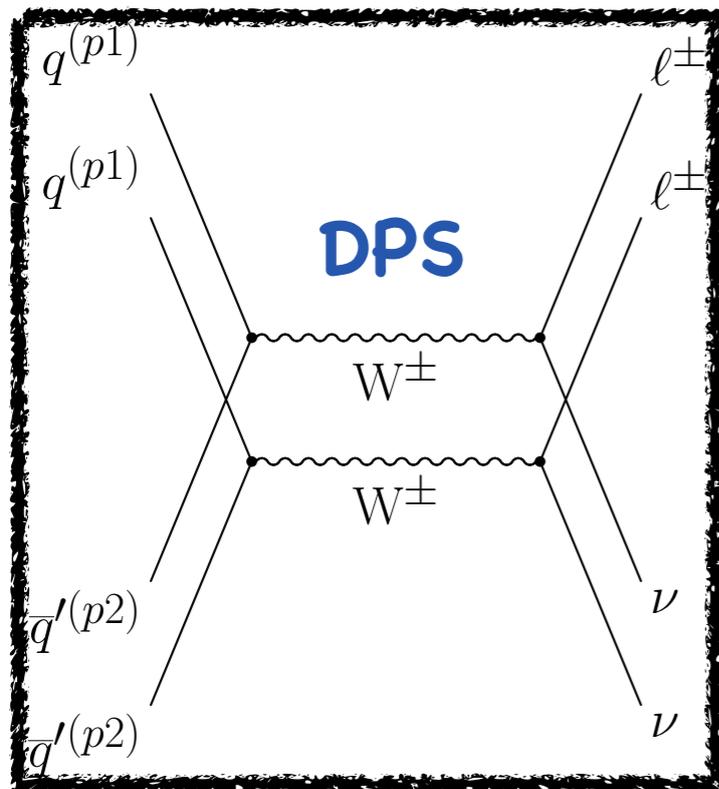
- Background contributions (photon conversions, top, DY, diboson, etc.) estimated from MC simulations except for nonprompt leptons

- Measured total cross sections consistent with theoretical calculations at combined NNLO QCD and NLO QED





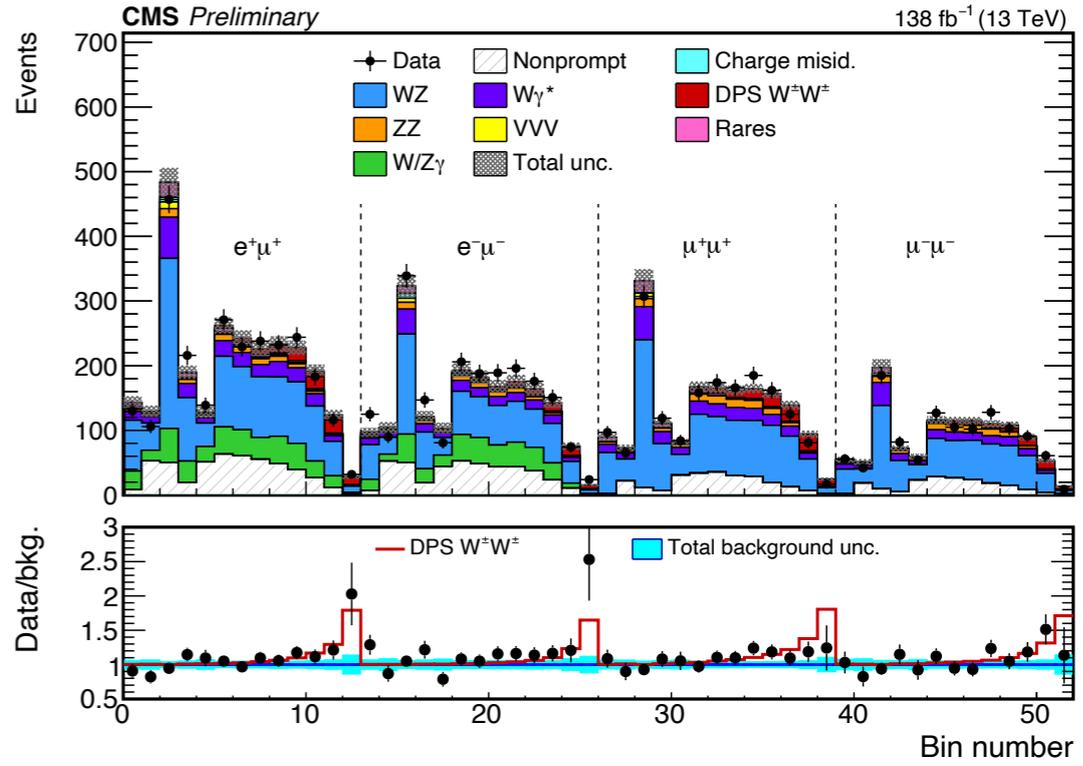
$W^\pm W^\pm$ via double parton scattering



- Golden channel to study DPS since SPS $W^\pm W^\pm$ production suppressed due to presence of (two) extra jets
- Non-factorization models \rightarrow Parton correlations in terms of spin, color, momentum, etc.
- Insensitive to pileup effects & clean final state with leptonic W decays
- Analysis performed with $WW \rightarrow e\mu/\mu\mu + \text{MET}$ final states using 138 fbinv

W±W± via double parton scattering (cont.)

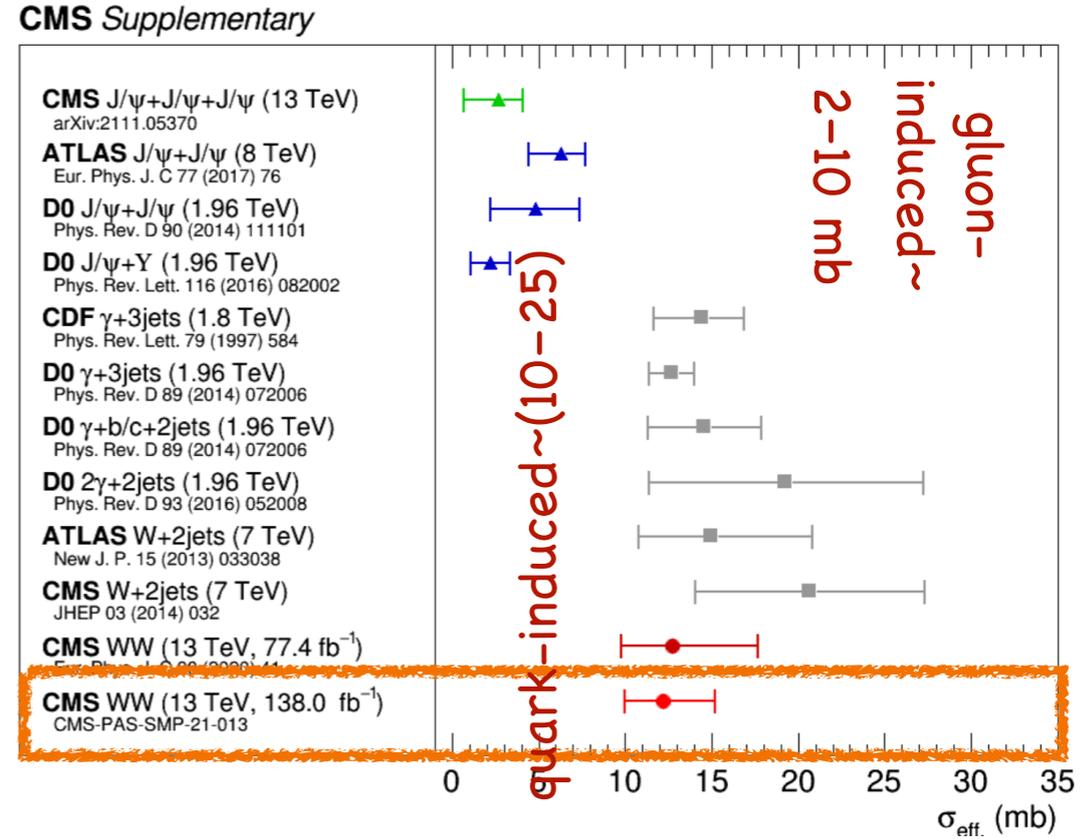
- Dominant background contributions from WZ and nonprompt leptons
- Signal & background discrimination based on BDT
- First observation of W±W± via DPS with 6.2σ obs. (6.7σ exp.)



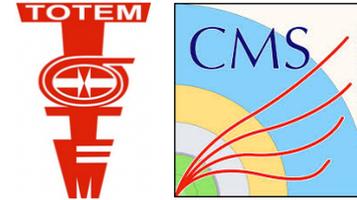
- Measured inclusive & fiducial cross sections in agreement with predictions;

$$\sigma_{AB}^{DPS} = \frac{n}{2} \frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

- Effective cross section → Transverse size of the proton
- Sensitivity towards parton correlations is limited by statistics



Process-dependent ??



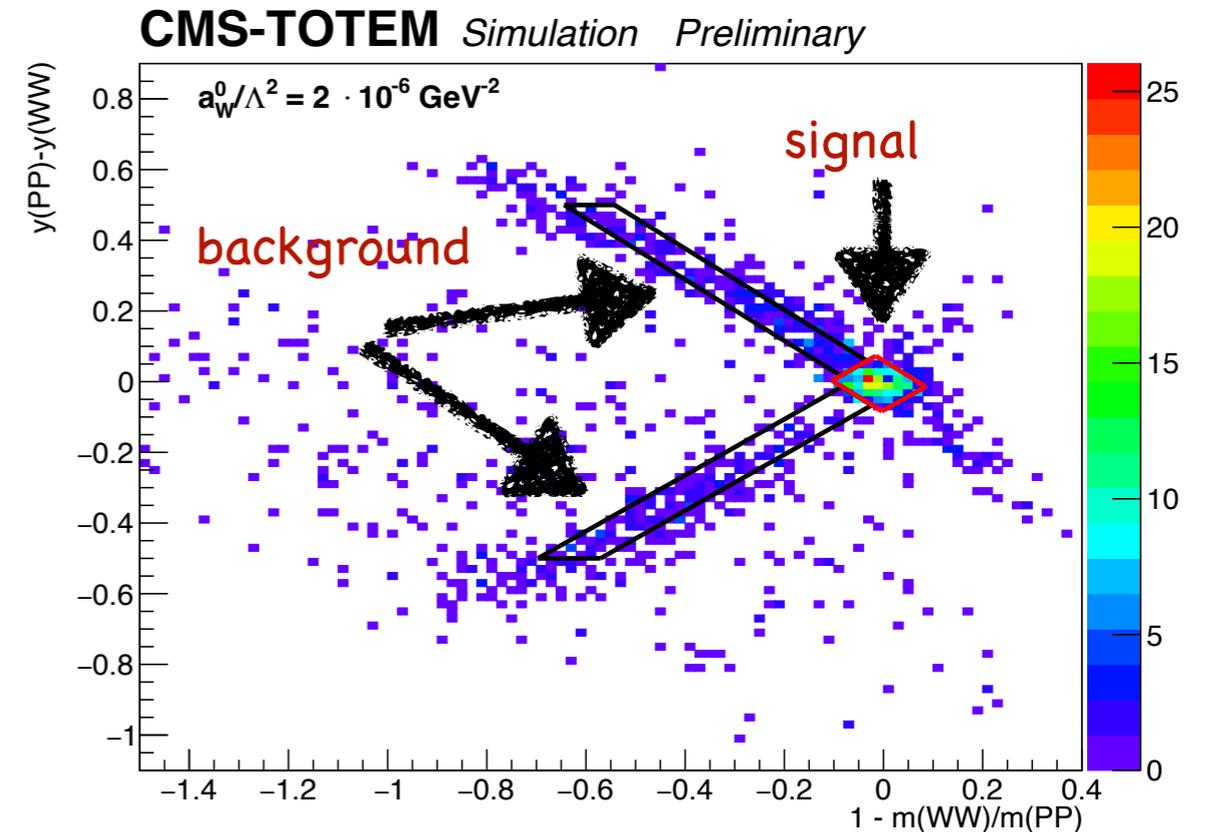
Exclusive WW and ZZ production

- First search for anomalous high mass $\gamma\gamma \rightarrow WW/ZZ$ in hadronic final state

$\sigma(\gamma\gamma \rightarrow WW)$ in SM $\sim 87\text{fb}$ @13TeV

$\gamma\gamma \rightarrow ZZ$ not allowed at tree-level in SM

- 100 fbinv CMS + Precision Proton Spectrometer (PPS)
- Near-beam detectors $\sim 200\text{m}$ from CMS IP
- W/Z bosons in CMS & protons in PPS

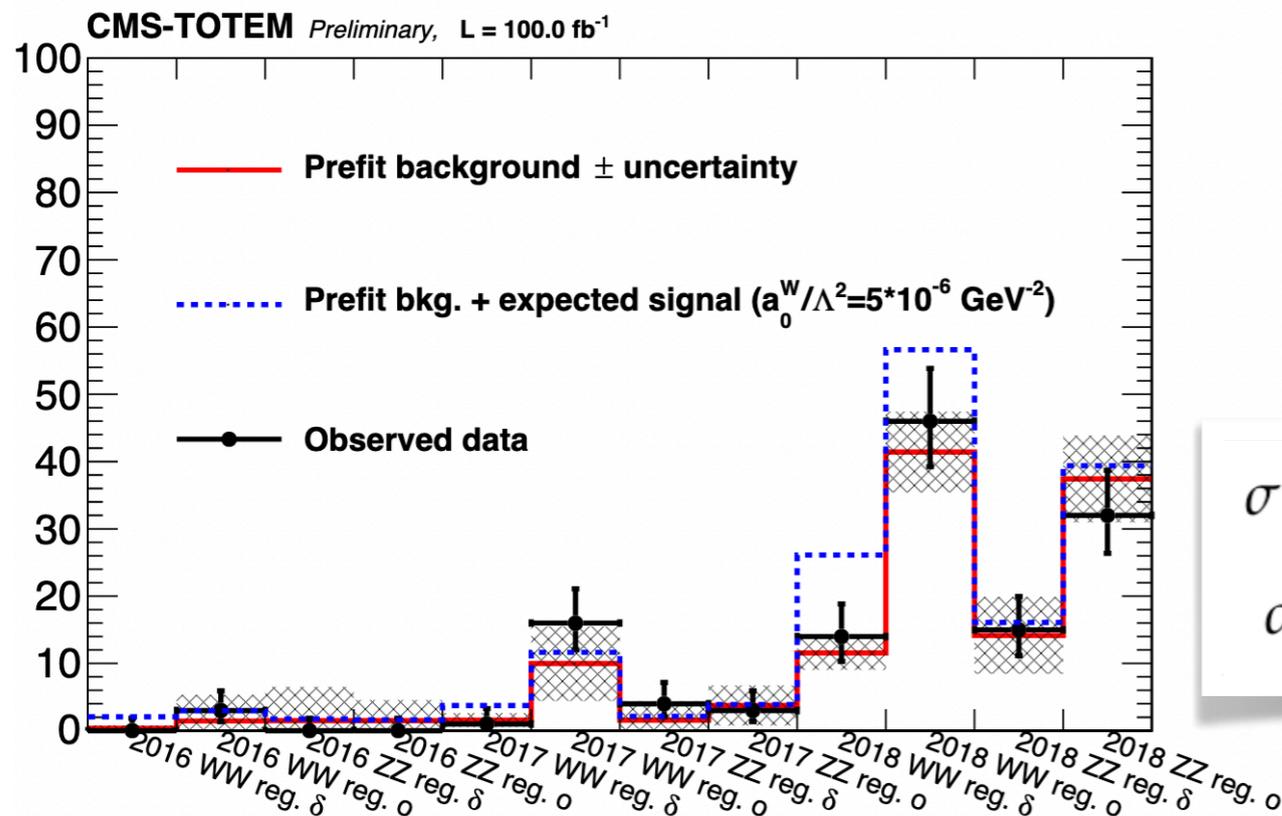


No significant excess over background only hypothesis

Limits on fiducial xsec for aQGC-like signal

$$\sigma(pp \rightarrow pWWp)_{0.04 < \xi < 0.20, m > 1000 \text{ GeV}} < 67 (53_{-19}^{+34}) \text{ fb},$$

$$\sigma(pp \rightarrow pZZp)_{0.04 < \xi < 0.20, m > 1000 \text{ GeV}} < 43 (62_{-20}^{+33}) \text{ fb},$$

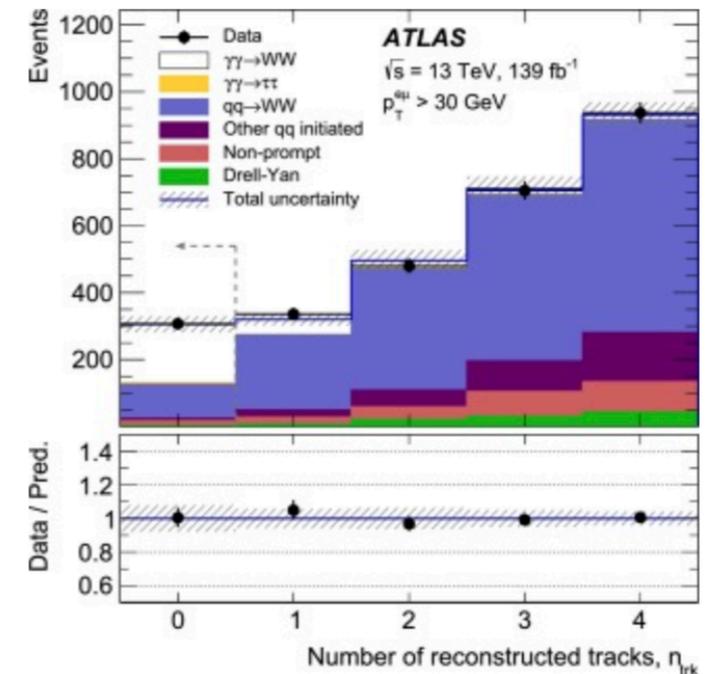
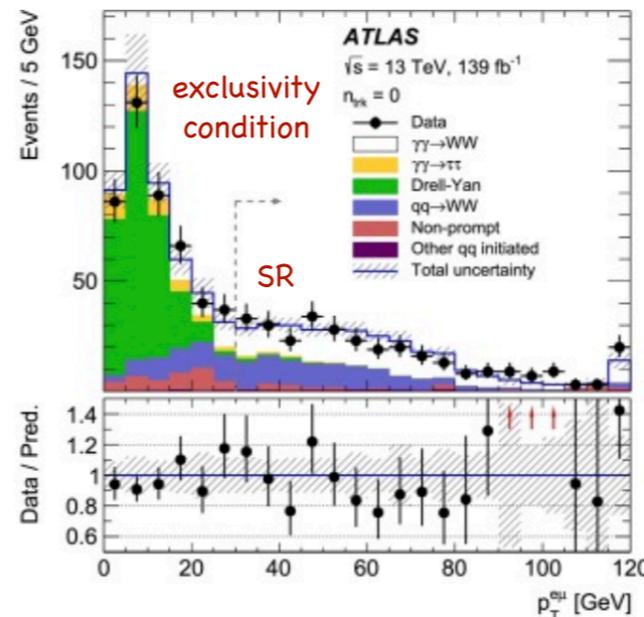
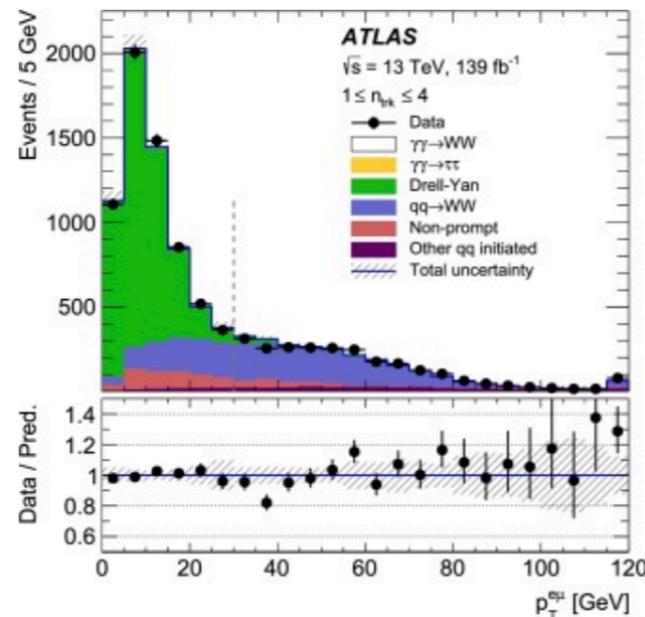


$\gamma\gamma \rightarrow WW$

- $pp(\gamma\gamma) \rightarrow p(*)WWp(*) \rightarrow e\mu$ with 139 fb⁻¹
- Elastic, single-dissociative, and double-dissociative WW production
- Two leptons with no additional charged-particle activity in the detector
 - Reduction in background from quark- and gluon-induced WW and t \bar{t} productions



signal & background control regions based on $p_T^{e\mu}$



Obs. sig > 5 σ

Measured cross section in agreement with theoretical predictions

Summary

- Plenty of great measurements with run2 → Precision era
- More analyses in pipeline with improved physics object reconstruction and performances, more variables for differential cross section measurements, final states etc.
- In general a fair agreement between data and theory predictions
- Some analyses limited by statistics → Interesting opportunities for run3
- What can we do more/new with run3?

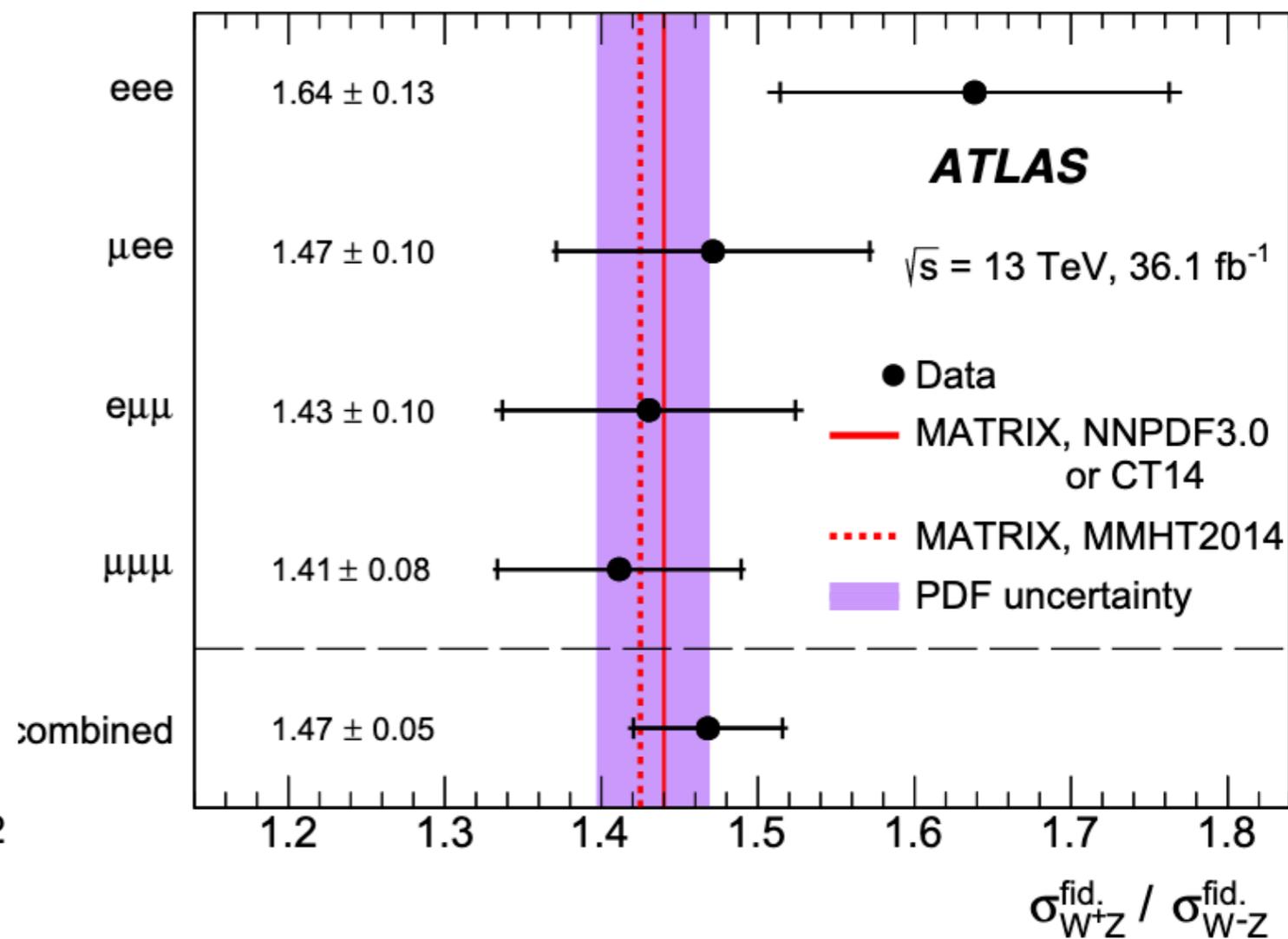
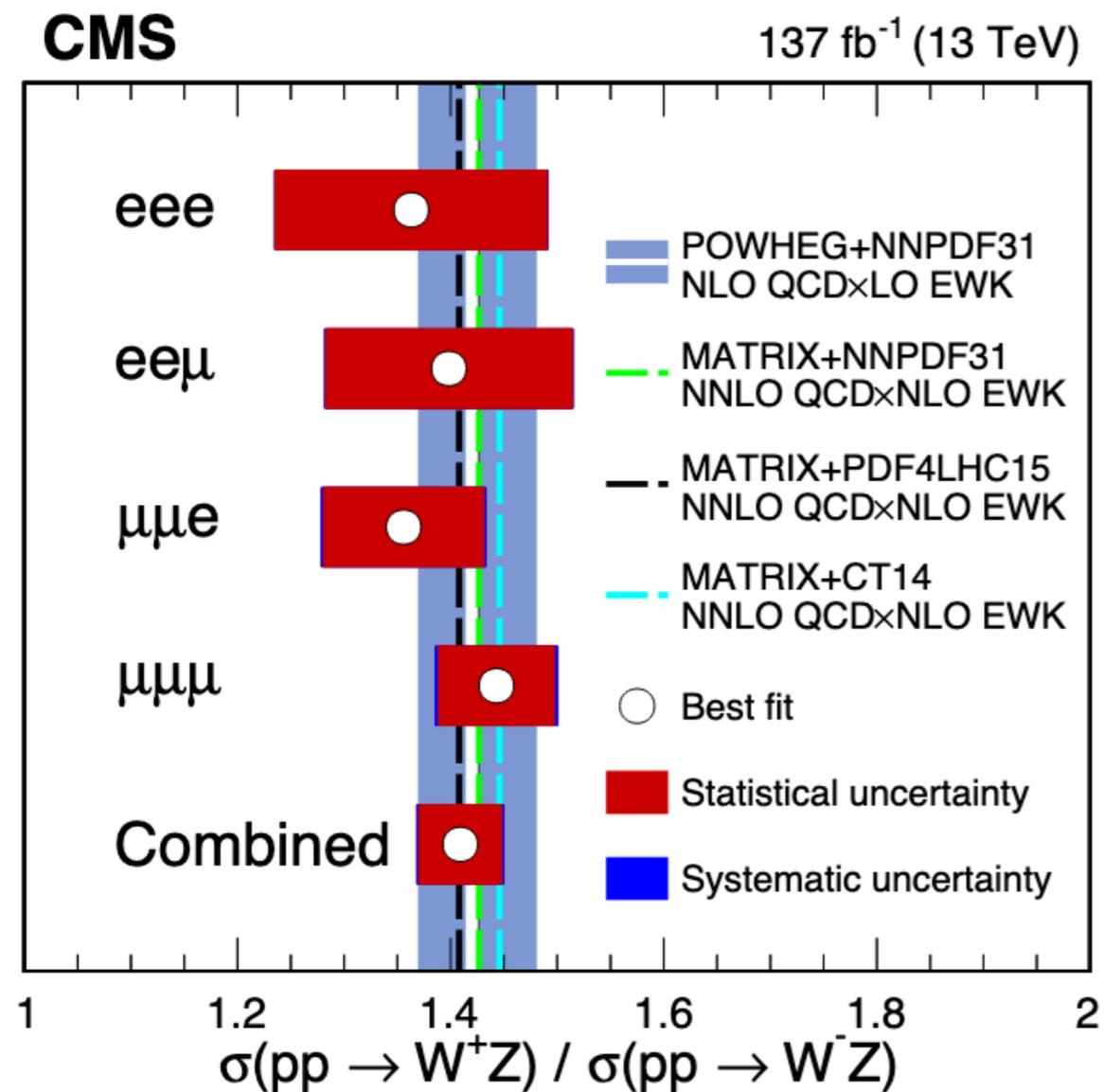
<https://cms-results-search.web.cern.ch/>

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults>

backup



$WZ \rightarrow 3lv$ channel

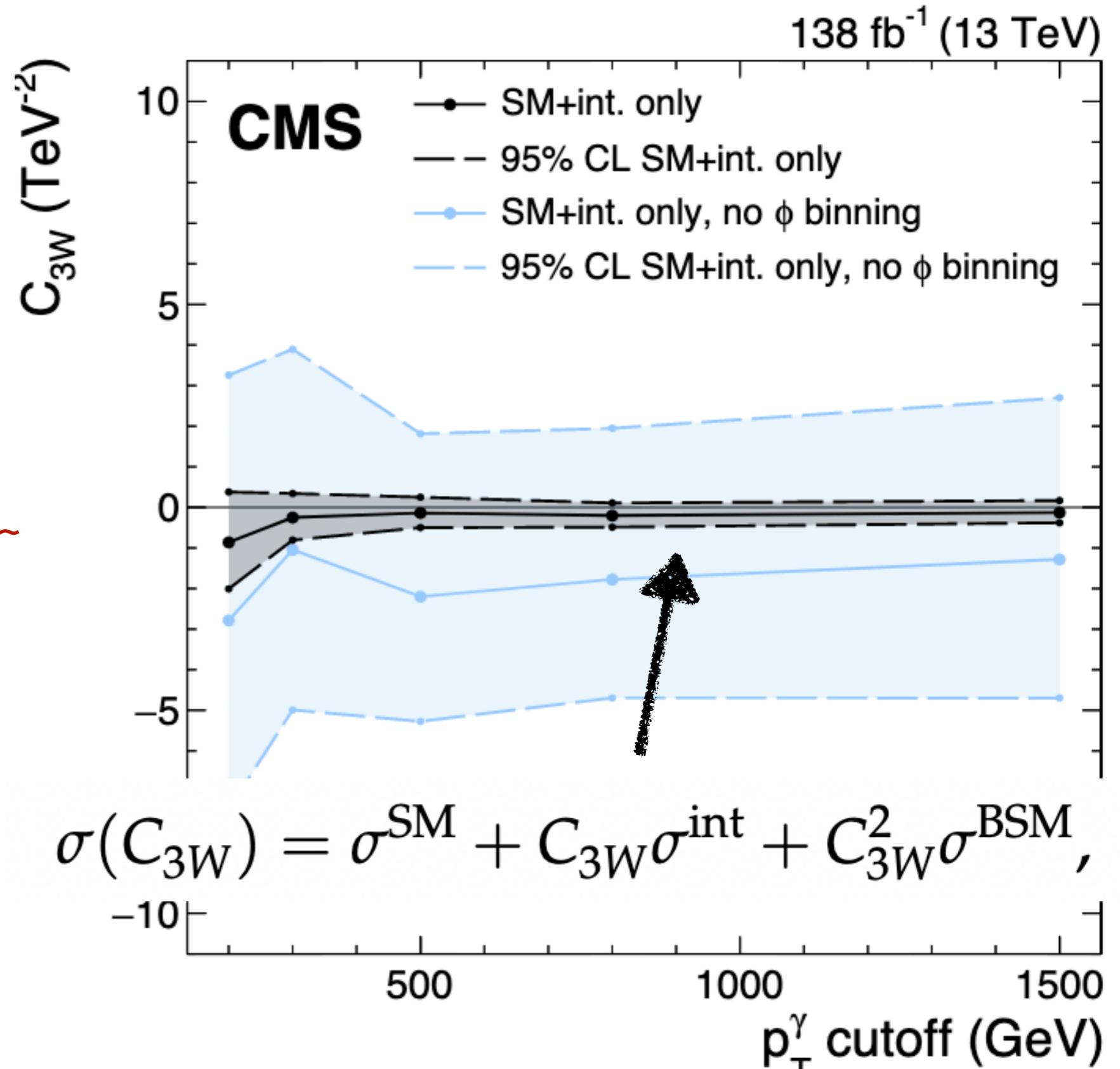


Statistics-dominated
Sensitive to pdfsets



Wy

- Interference resurrection
- Sensitivity to SM-dim6 interference enhanced ~ by a factor of 10

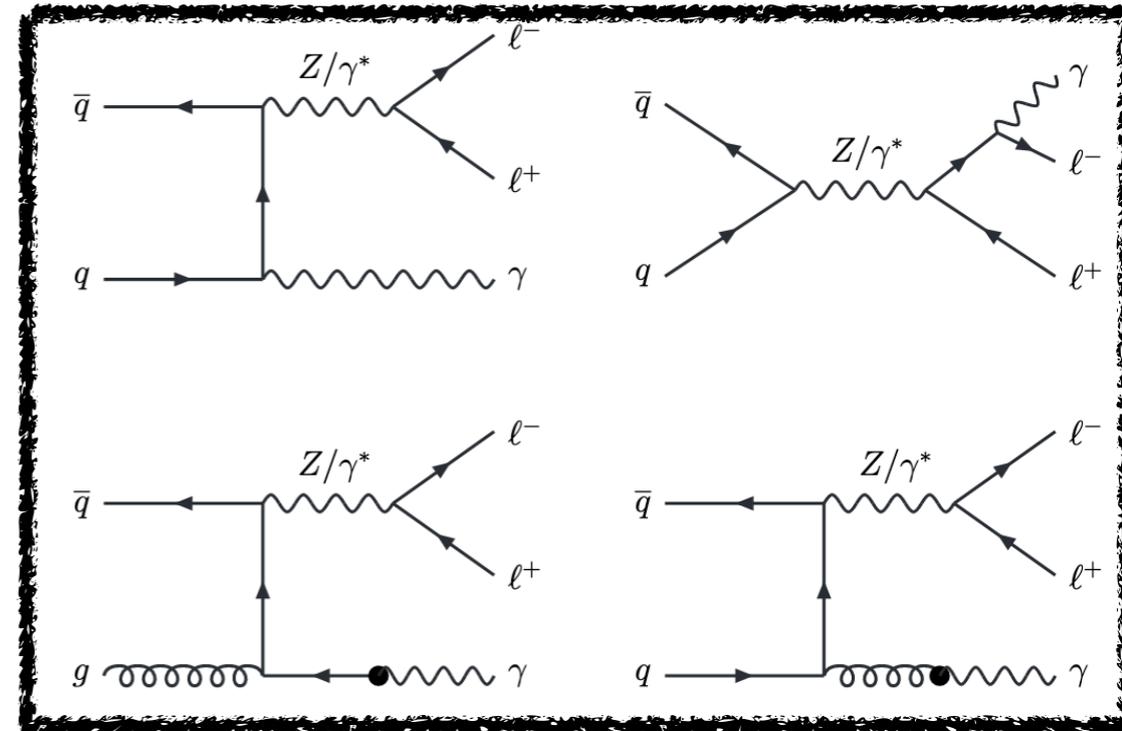




- Differential cross section measurement over a wider range of E_T^γ
- EW $Z\gamma jj$ considered to be part of the signal

Integrated fiducial cross section

	Cross-section [fb]		
$e^+e^-\gamma$	530.4	± 9.0 (uncorr)	± 11.7 (corr) ± 9.0 (lumi)
$\mu^+\mu^-\gamma$	535.0	± 6.1 (uncorr)	± 11.5 (corr) ± 9.1 (lumi)
$\ell^+\ell^-\gamma$	533.7	± 5.1 (uncorr)	± 11.6 (corr) ± 9.1 (lumi)
SHERPA LO	438.9	± 0.6 (stat)	
SHERPA NLO	514.2	± 5.7 (stat)	
MADGRAPH NLO	503.4	± 1.8 (stat)	
MATRIX NLO	444.2	± 0.1 (stat)	± 4.3 (C_{theory}) ± 8.8 (PDF) $^{+16.8}_{-18.9}$ (scale)
MATRIX NNLO	518.9	± 2.0 (stat)	± 5.1 (C_{theory}) ± 10.8 (PDF) $^{+16.4}_{-14.9}$ (scale)
MATRIX NNLO \times NLO EW	513.5	± 2.0 (stat)	± 2.7 (C_{theory}) ± 10.8 (PDF) $^{+16.4}_{-14.9}$ (scale)
MATRIX NNLO + NLO EW	518.3	± 2.0 (stat)	± 2.7 (C_{theory}) ± 10.8 (PDF) $^{+16.4}_{-14.9}$ (scale)



- Measured cross section 20(4-6)% higher than LO (NLO & NNLO)

- Precision $\sim 3-7\%$ except for the (statistically limited) two highest bins (15%)

