Studying the Electroweak Sector with the ATLAS Detector

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On behalf of the ATLAS Collaboration

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Outline

➢ Physics motivations

➢ Electroweak related results

- Precision measurements with single W/Z bosons

- Diboson productions

- Triboson productions

- Measurements of rare processes

➢ Summary

Electroweak physics

➤ **W/Z boson decays**
  - Precision measurement of W mass, weak mixing angle…

➤ **Di-boson production**
  - involves triple gauge couplings(TGC)

➤ **Triple-boson production**
  - involves quartic gauge couplings(QGC)

➤ **Electroweak production of vector boson: VBS, VBF**
  - involves QGC
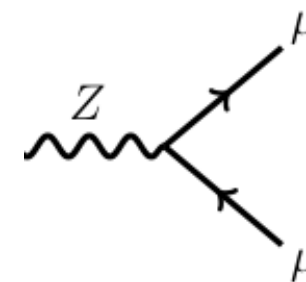 - sensitive to the electroweak symmetry breaking

✓ Test of the electroweak theory
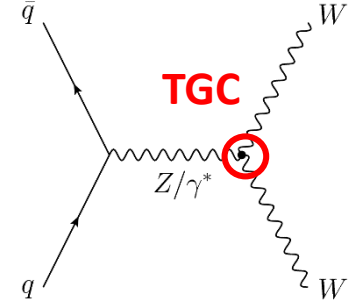✓ Search for new physics: anomalous TGC(aTGC), anomalous QGC(aQGC)
✓ Study of the electroweak symmetry breaking(EWSB) mechanism
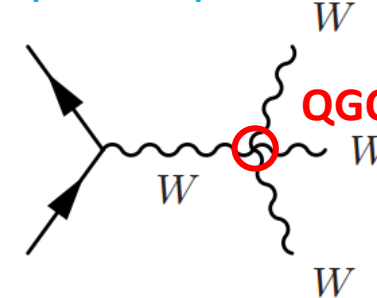✓ Important background to many new physic searches and studies
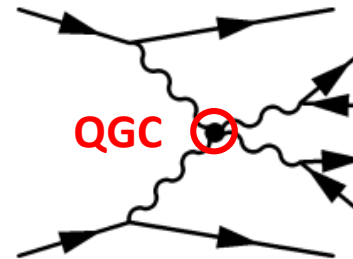
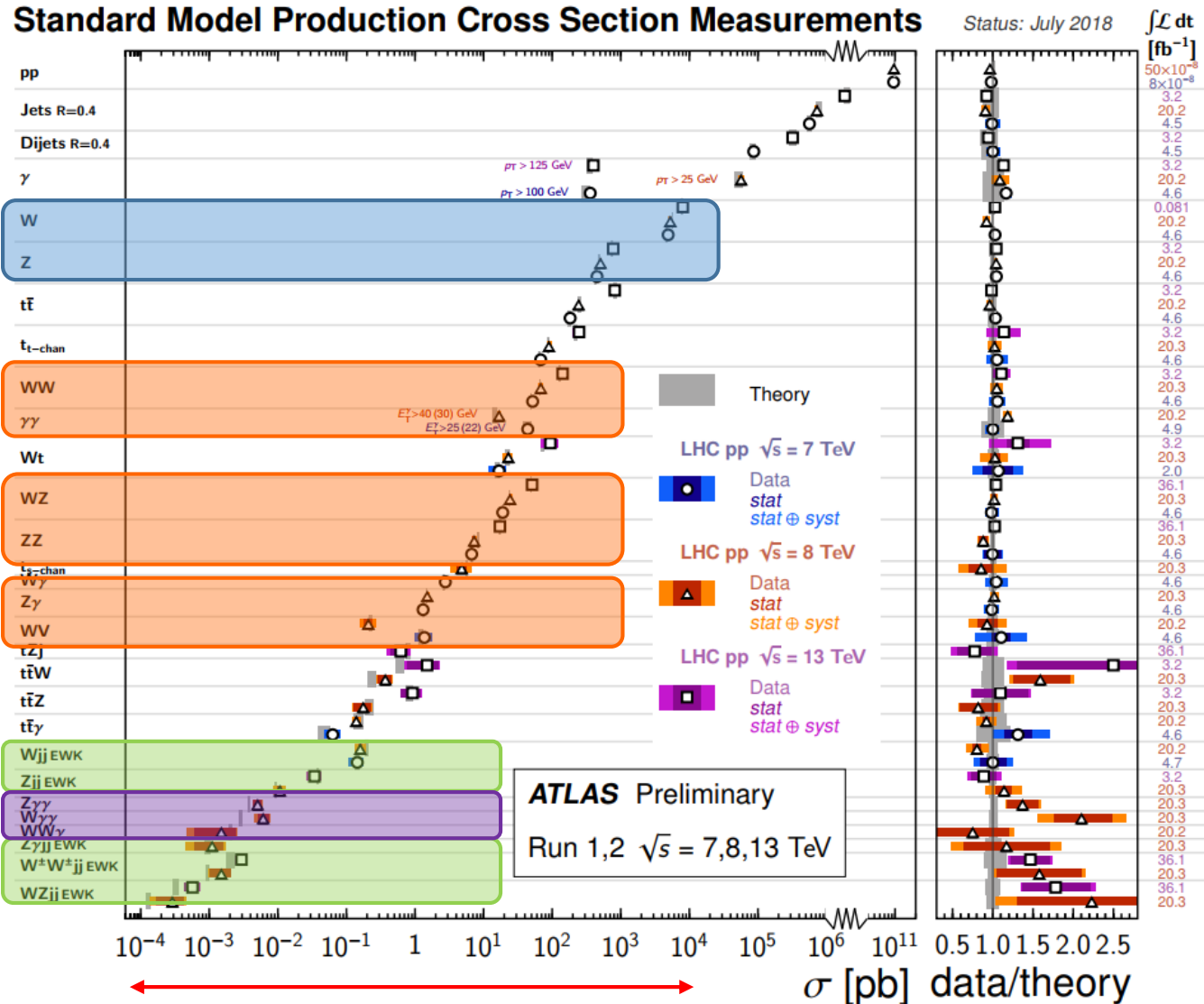**Z boson decay**

Di-boson production

Triple-boson production

VBS

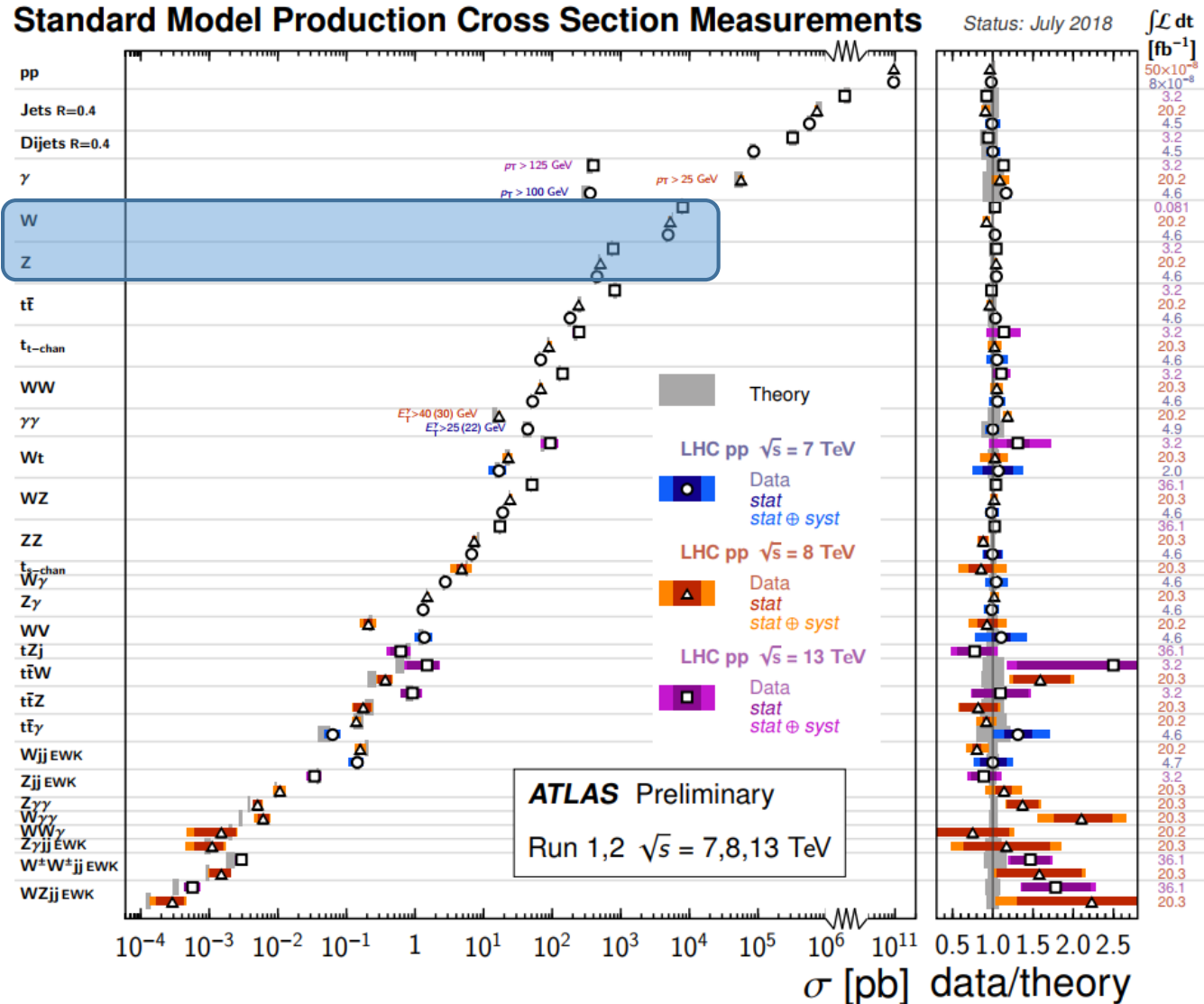# (Multiple) Vector boson production with the ATLAS

- **Single W/Z bosons**

- **Diboson production**

- **Triboson production**

- **Rare processes VBS, VBF**

➢ Cross sections of electroweak processes at the ATLAS span eight orders of magnitude

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Precision measurements with single W/Z boson

- **Single W/Z bosons**

- Diboson production

- Triboson production

- Rare processes VBS, VBF

Precision measurements with single W/Z boson

➢ Precision measurements have been performed with single W/Z boson at 7/8 TeV

- W mass measurement at 7 TeV
  [Eur. Phys. J. C 78 (2018) 110]

- weak mixing angle measurement at 7 TeV

  [JHEP09(2015)049]

➢ 3 latest ATLAS results using 20.2 fb−1 data at 8 TeV in this talk:

- 3D cross-section in Z/γ* → ll at 8 TeV
- Tau polarisation in Z/γ* → ττ at 8 TeV
- $\sin^2\theta_{eff}^{lep}$ in Z/γ* → ll at 8 TeV

W mass measurement at 7 TeV

weak mixing angle measurement at 7 TeV
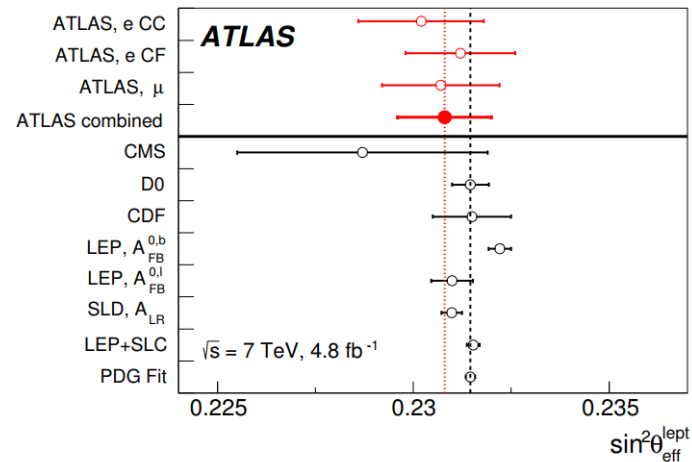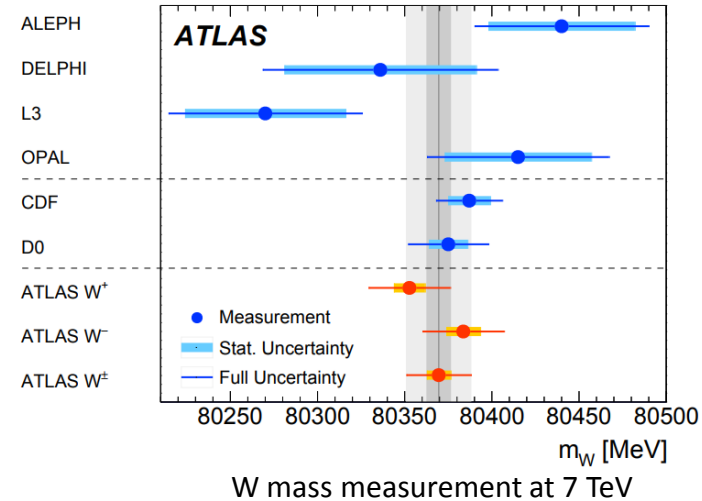
Tau polarisation in Z/γ* → ττ at 8 TeV

- Select tau decay channel of Z/γ* → ττ
  - One τ is hadronic decay
  - One τ is leptonic decay
- Major background: multijet, W+jets
- Signal MC: Alpgen
- Two channel in final state:
  - $\tau_e - \tau_{had}$ • $\tau_\mu - \tau_{had}$
- Hadronic decay τ is used to measure polarization
  - Sensitive decay modes: $\tau^\pm \to h^\pm \nu$, $\tau^\pm \to h^\pm \pi^0 \nu$
  - Observable: asymmetry of energies carried by charged and neutral pion

$$\Upsilon = \frac{E_{\pi^\pm} - E_{\pi^0}}{E_{\pi^\pm} + E_{\pi^0}} = 2\frac{p_T^{track}}{E_T^{\tau_{had-vis}}} - 1$$

- Two regions are defined for polarization extraction
  - Fiducial region
  - Mass-selected region ($66 < M_{Z/\gamma^*} < 116$ GeV)

- Maximum likelihood fit to the ϒ distribution
- Results are in good agreement with Standard Model prediction
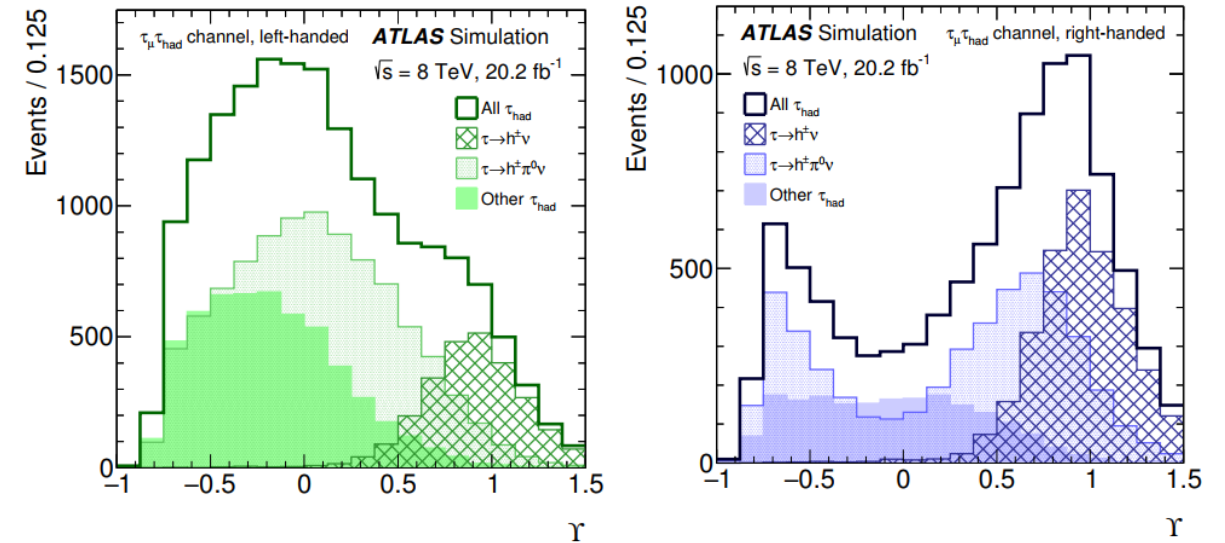
Channel	P_τ in mass-selected region	P_τ in fiducial region
Combination	-0.14±0.02(stat) ±0.04(syst)	-0.27±0.02(stat) ±0.04(syst)
SM prediction	-0.1517 ± 0.0019	-0.270 ± 0.006

3D cross-section in Z/γ* → ll at 8 TeV

- Select leptonic decay of Z/γ* → ll decays
  - ee and μμ channels in central region ($|y_{ll}| < 2.4$)
  - ee in high-rapidity region ($|y_{ll}| < 3.6$)
- Major background: Z/γ* → ττ, diboson, Top, multijet
- Signal MC: Powheg

➤ triple-differential cross section is sensitive to weak mixing angle and the PDFs

➤ Differential cross section is published differentially in:

- $m_{ll}, y_{ll}, cos\theta^*$
- m_{ll}, y_{ll}
- m_{ll}

➤ A_{FB}, forward-backward asymmetry is derived from the triple-differential cross-section measurements

$$A_{FB} = \frac{d^3\sigma(\cos\theta^* > 0) - d^3\sigma(\cos\theta^* < 0)}{d^3\sigma(\cos\theta^* > 0) + d^3\sigma(\cos\theta^* < 0)}$$
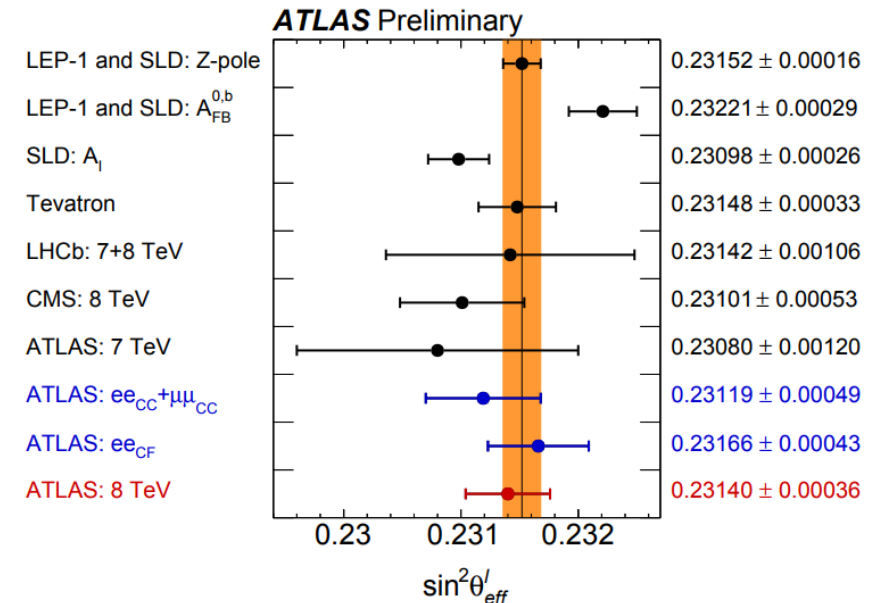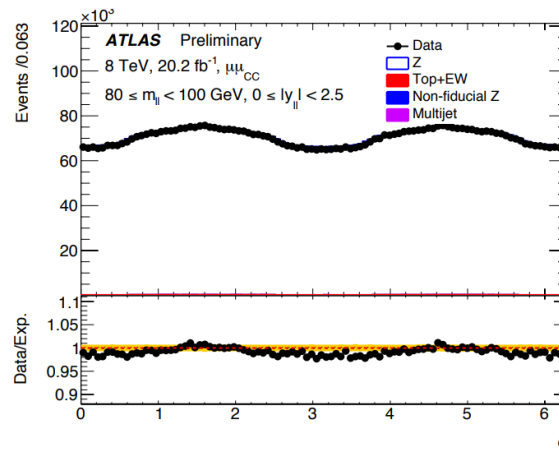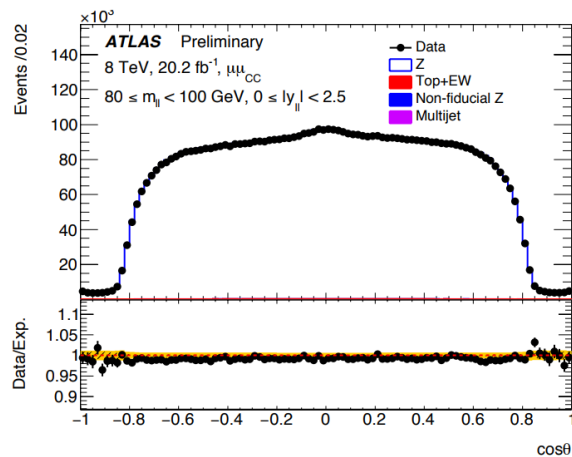
➤ Good Agreement with SM prediction
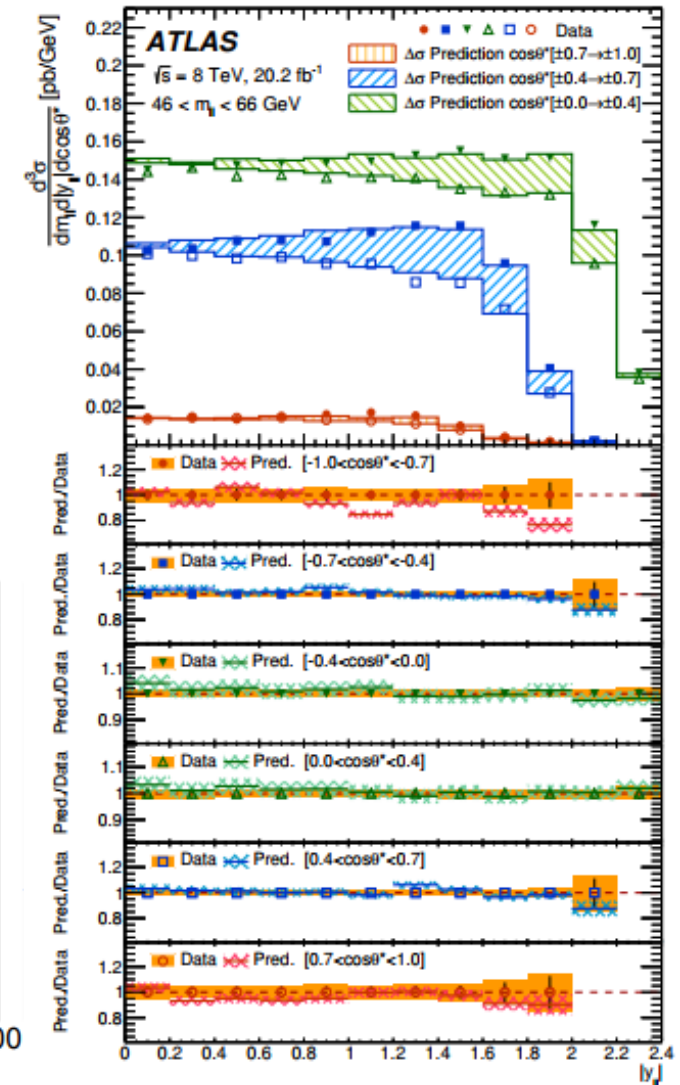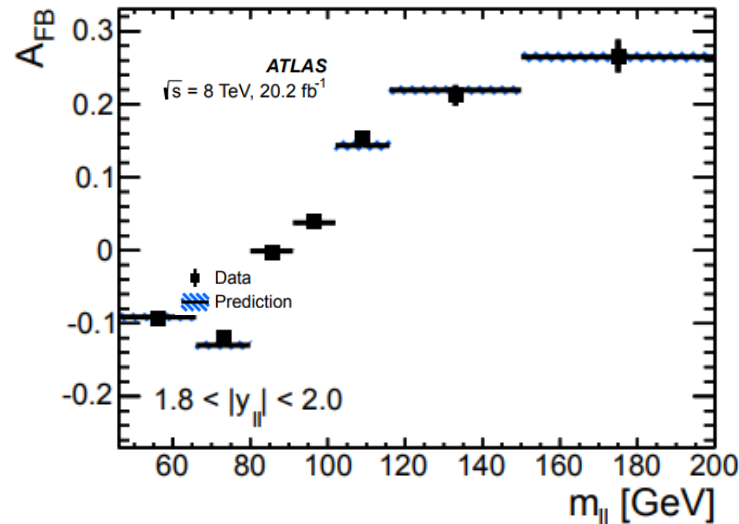
$\sin^2\theta_{eff}^{lep}$ in Z/γ* → ll at 8 TeV

- Select leptonic decay of Z/γ* → ll
  - ee and μμ channels in central region ee_{CC}, $\mu\mu_{CC}$ ($|y_{ll}| < 2.4$)
  - ee in high-rapidity region ee_{CF} ($|y_{ll}| < 3.6$)
- Major background: Z/γ* → ττ, diboson, Top, multijet
- Signal MC: Powheg
- ➤ The full five-dimensional differential cross-section can be decomposed as nine polynomials $P_i(cos\theta, \phi)$ with eight angular coefficients A_i, multiplied by corresponding unpolarised cross-sections

- ➤ The angular coefficient A_4 is sensitive to $\sin^2\theta_{eff}^{lep}$

- ➤ The angular coefficients are extracted by fitting templates of the P_i polynomial terms to the reconstructed angular distributions in $(cos\theta, \phi)$ space

- ➤ The extraction of $\sin^2\theta_{eff}^{lep}$ proceeds by parameterizing A_4 directly in the likelihood via a linear interpolation model derived from predictions

$$A_4\left(sin^2\theta_{eff}^{lep}\right) = a \times sin^2\theta_{eff}^{lep} + b$$


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Diboson productions

- Single W/Z bosons

- **Diboson production**

- Triboson production

- Rare processes VBS, VBF
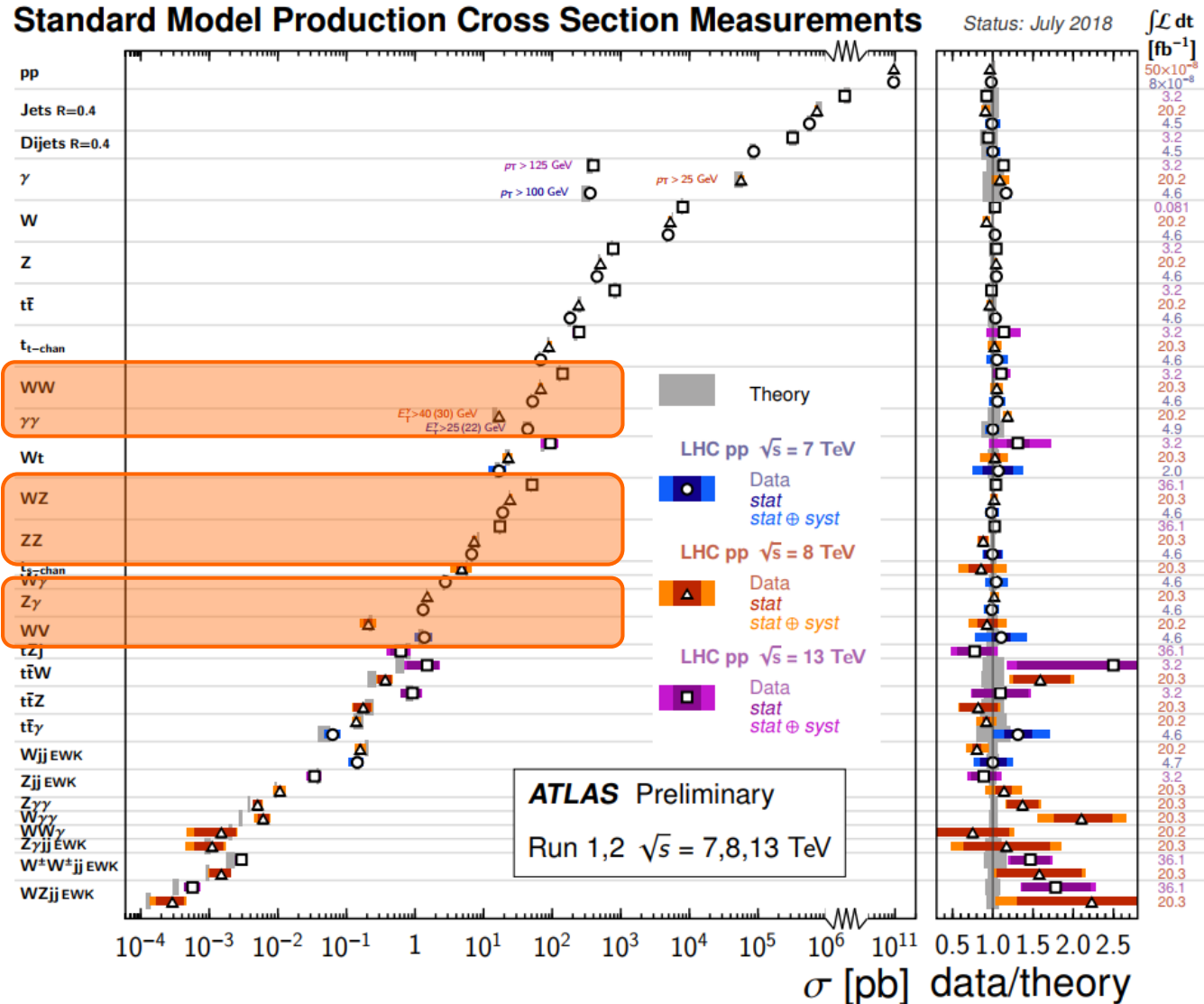
Diboson productions

➤ WW, WZ, ZZ: leptonic and semi-leptonic decay channels
  - Well measured at 7/8/13 TeV

➤ Generally good agreement with SM prediction

➤ 3 latest ATLAS results using 36.1 fb−1 data at 13 TeV in this talk:
  - Zγ →ννγ cross section at 13 TeV
  - WZ cross-section at 13 TeV
  - ZZ → 4l cross-section at 13 TeV
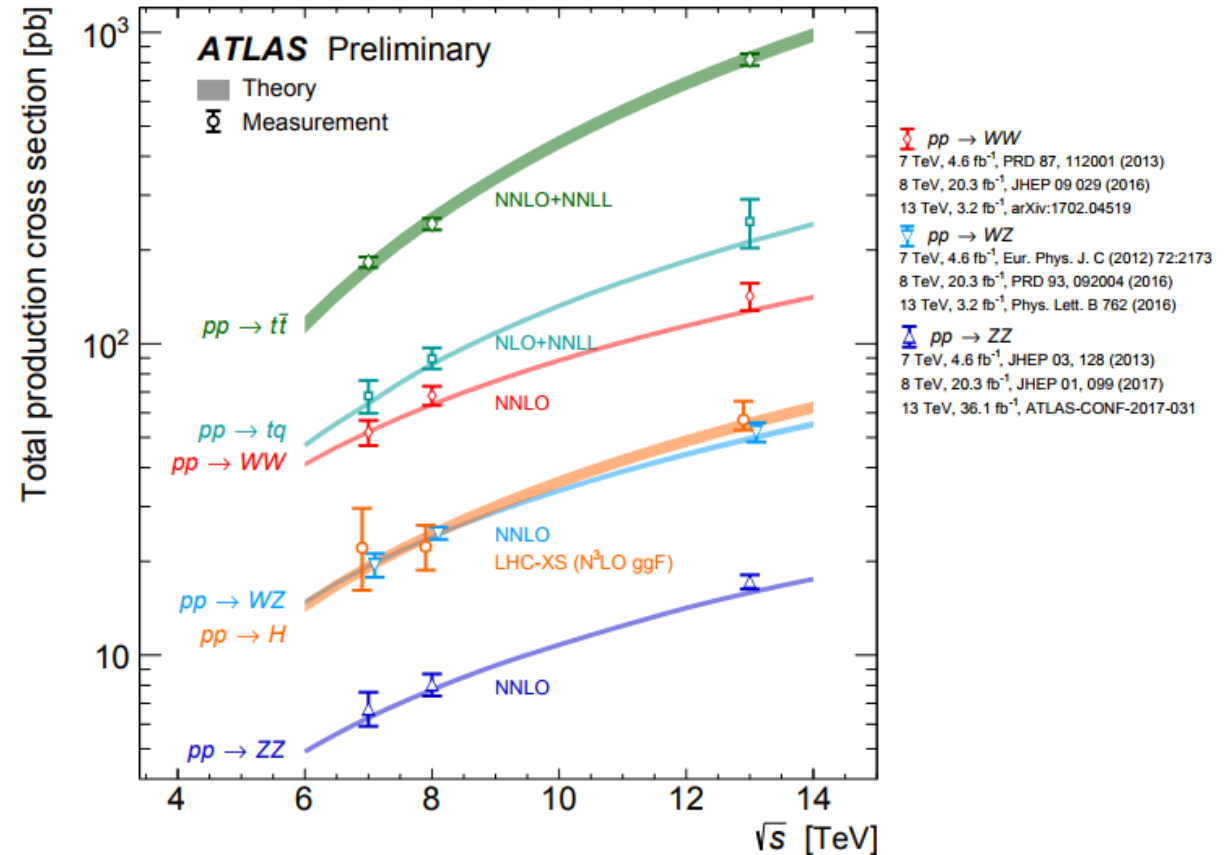
Zγ →ννγ cross section at 13 TeV

- Select neutrino decay channel of Zγ →ννγ
- Major background: W(lν)γ, W(e, ν), Z(ν, ν)
- Signal MC: Sherpa2.2.2

➢ The measured cross sections agree with the SM expectations within one standard deviation
➢ Differential cross section is measured as a function of variables
  - photon transverse energy E_T^γ
  - transverse momentum of neutrino-antineutrino pair $p_T^{\nu\bar\nu}$
  - jet multiplicity N_{jet}
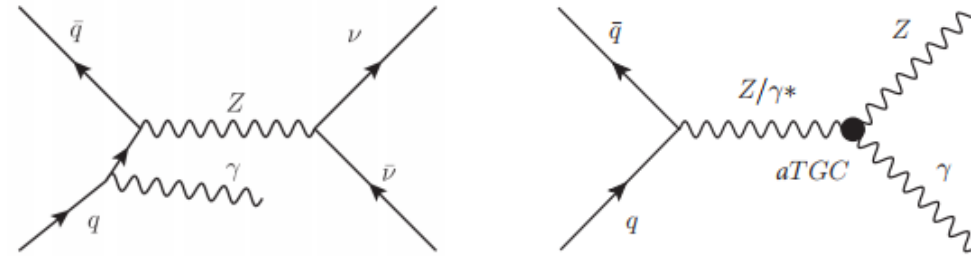
➢ aTGC is studied using Zγ events with high E_T^γ
➢ Confidence intervals of aTGC parameters are determined

|	$\sigma^{\text{ext.fid.}}$ [fb]	$\sigma^{\text{ext.fid.}}$ [fb]
	Measurement	NNLO MCFM Prediction
$N_{jets} \geq 0$		
	$83.7^{+3.6}_{-3.5}$ (stat.)$^{+6.9}_{-6.2}$ (syst.)$^{+1.7}_{-2.0}$ (lumi.)	78.1 ± 0.2(stat.)± 4.4(syst.)
$N_{jets} = 0$		
	$52.4^{+2.4}_{-2.3}$ (stat.)$^{+4.0}_{-3.6}$ (syst.)$^{+1.2}_{-1.1}$ (lumi.)	55.9 ± 0.1(stat.)± 2.5(syst.)
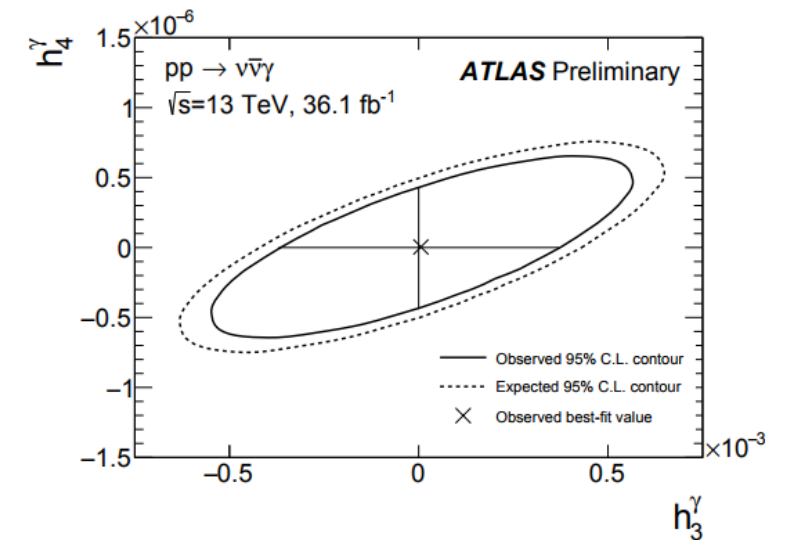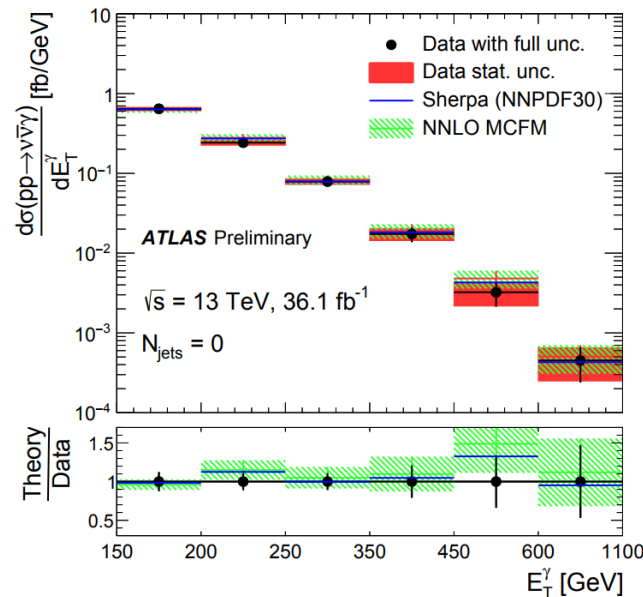
WZ cross-section at 13 TeV

- Select leptonic decay of WZ → three lepton final states (eee, eeμ, μμe, μμμ) +E_T^{miss}
- Major background: Z+jets, Top, ZZ, ttV
- Signal MC: Powheg

➤ The measured cross-sections are in good agreement with the SM predictions

➤ Differential cross-section is measured by adding all four decay channels together
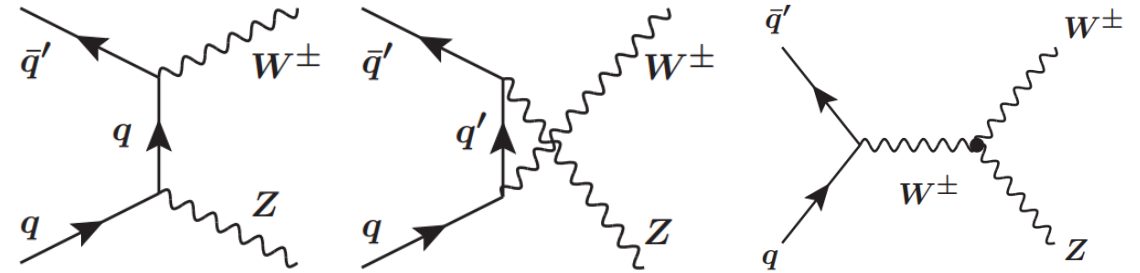
➤ W/Z polarization is measured using lepton angular distributions
➤ Template fit to $q_l \cdot cos\theta_{l,W}$ and of $cos\theta_{l,Z}$ distributions
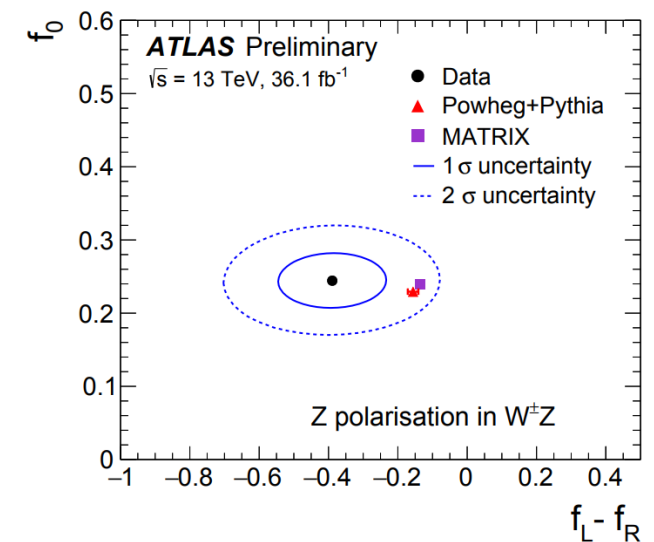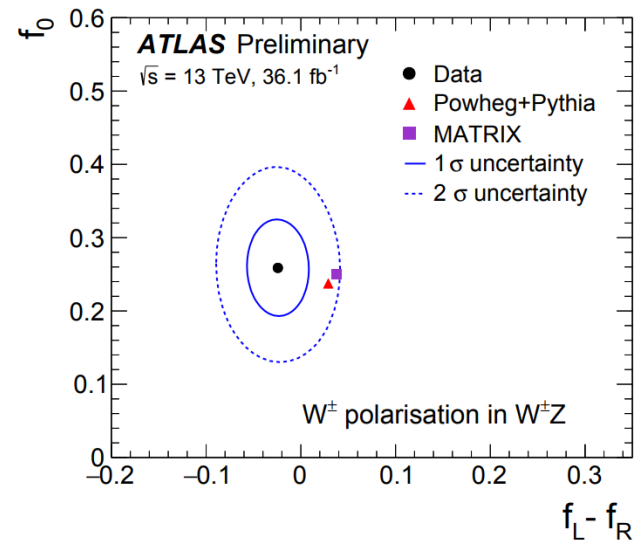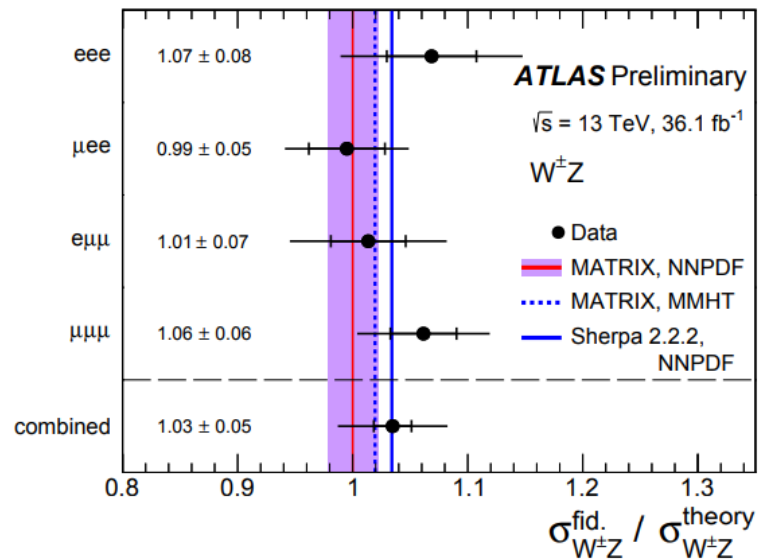
ZZ → 4l cross-section at 13 TeV

- Select leptonic decay of ZZ → four leptons
- Major background: triboson, Z+jets, Top
- Signal MC: Sherpa2.2.1

➤ Integrated fiducial cross sections are measured in three decay channels 4e, 2e2μ, and 4μ as well as in their combination

➤ Good Agreement with SM predictions

➤ Large dataset and clean final state allows the differential measurement for 20 observables
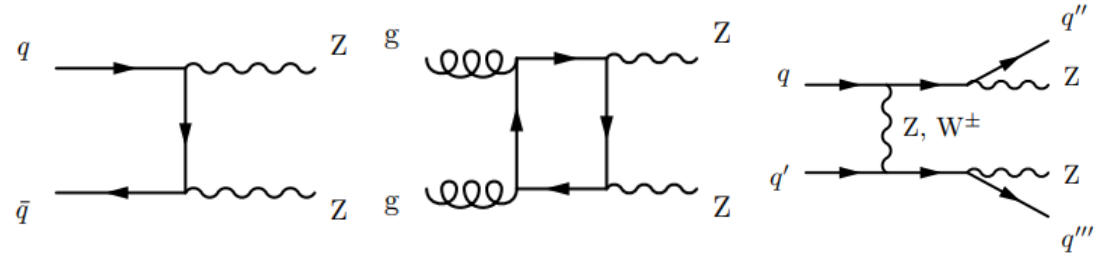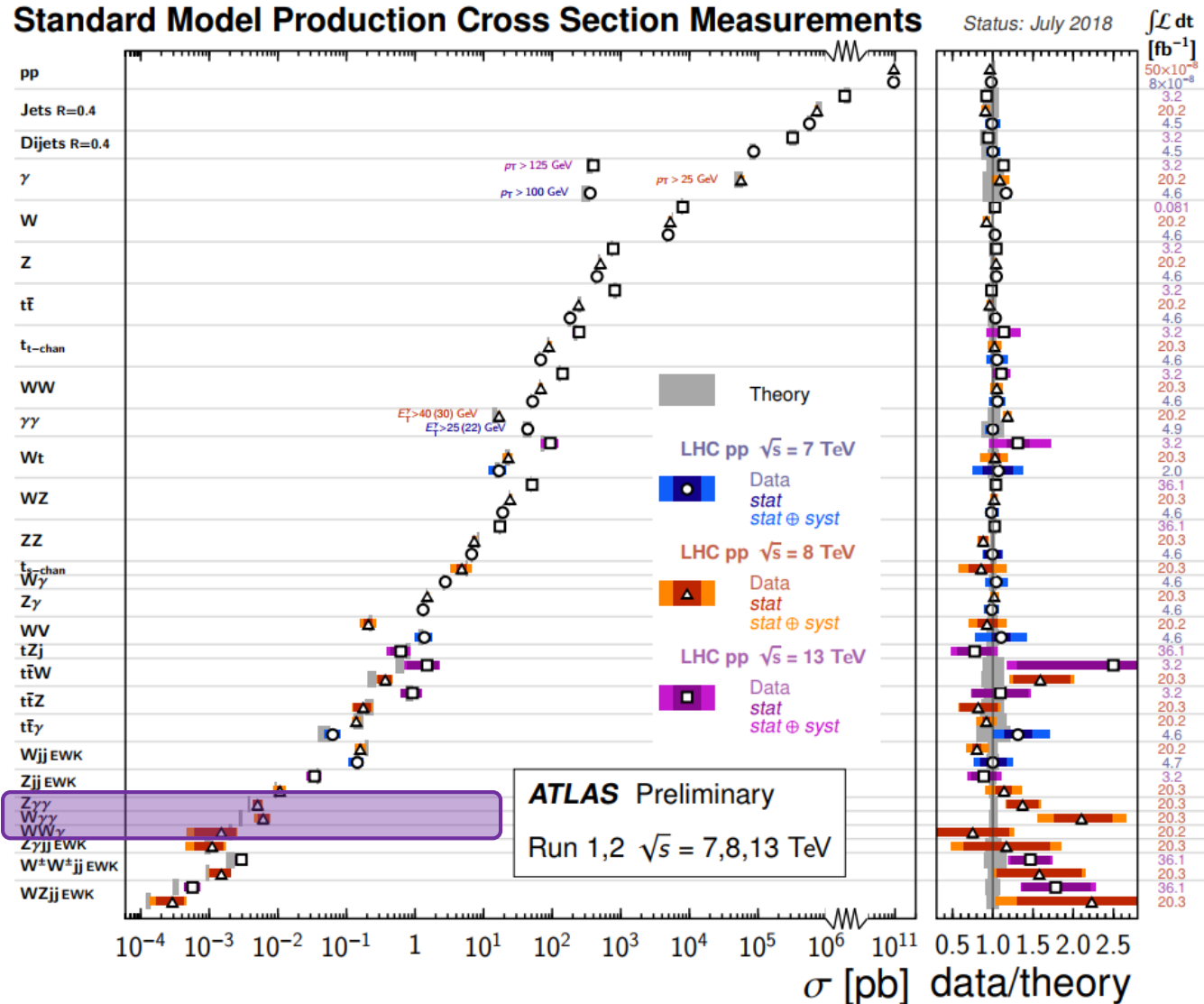
➤ aTGC is studied using reconstructed transverse momentum of the leading-p_T Z candidate

➤ Confidence intervals of aTGC parameters are determined
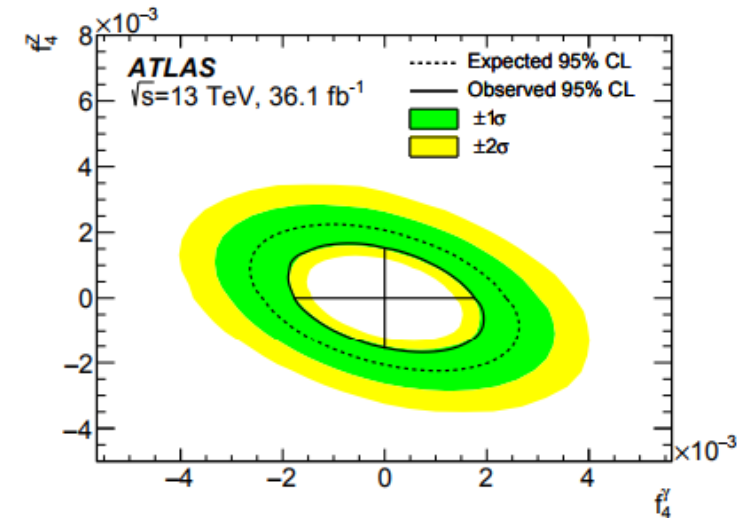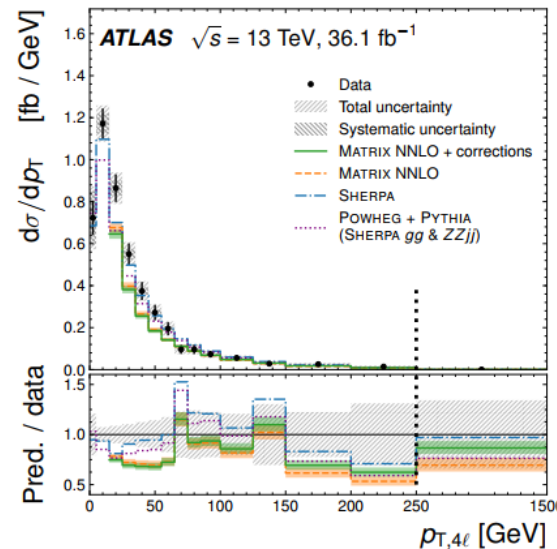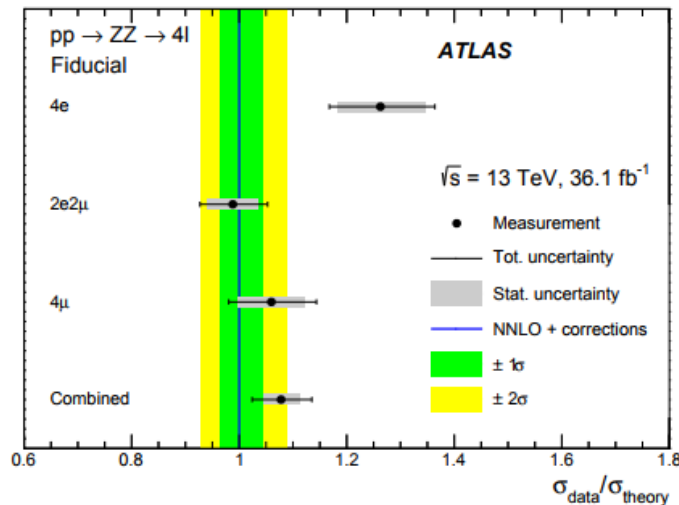
Triboson productions

- Single W/Z bosons

- Diboson production

- **Triboson production**
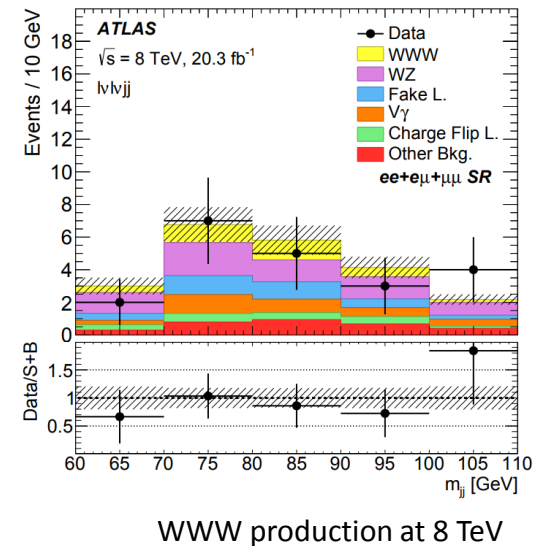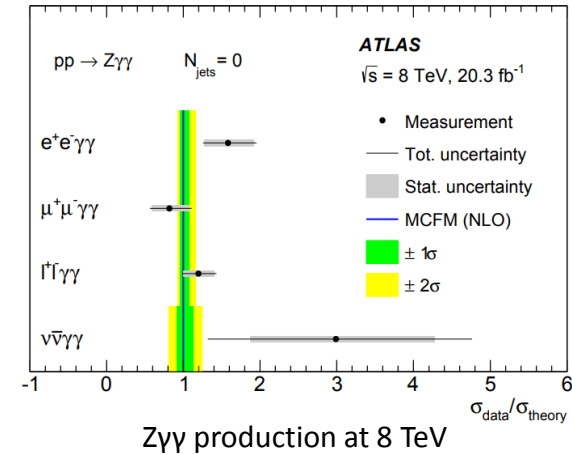
- Rare processes VBS, VBF

Triboson productions

➢ Tridoson productions have been measured at 8TeV

- • Wγγ production at 8 TeV
  [Phys. Rev. Lett. 115, 031802 (2015)]

- • Zγγ production at 8 TeV
  [Phys. Rev. D 93 (2016) 112002]

- • ZVγ production at 8 TeV
  [Eur. Phys. J. C 77 (2017) 141]

- • WWW production at 8 TeV
  [Eur. Phys. J. C 77 (2017) 646]

➢ Generally good agreement with SM prediction

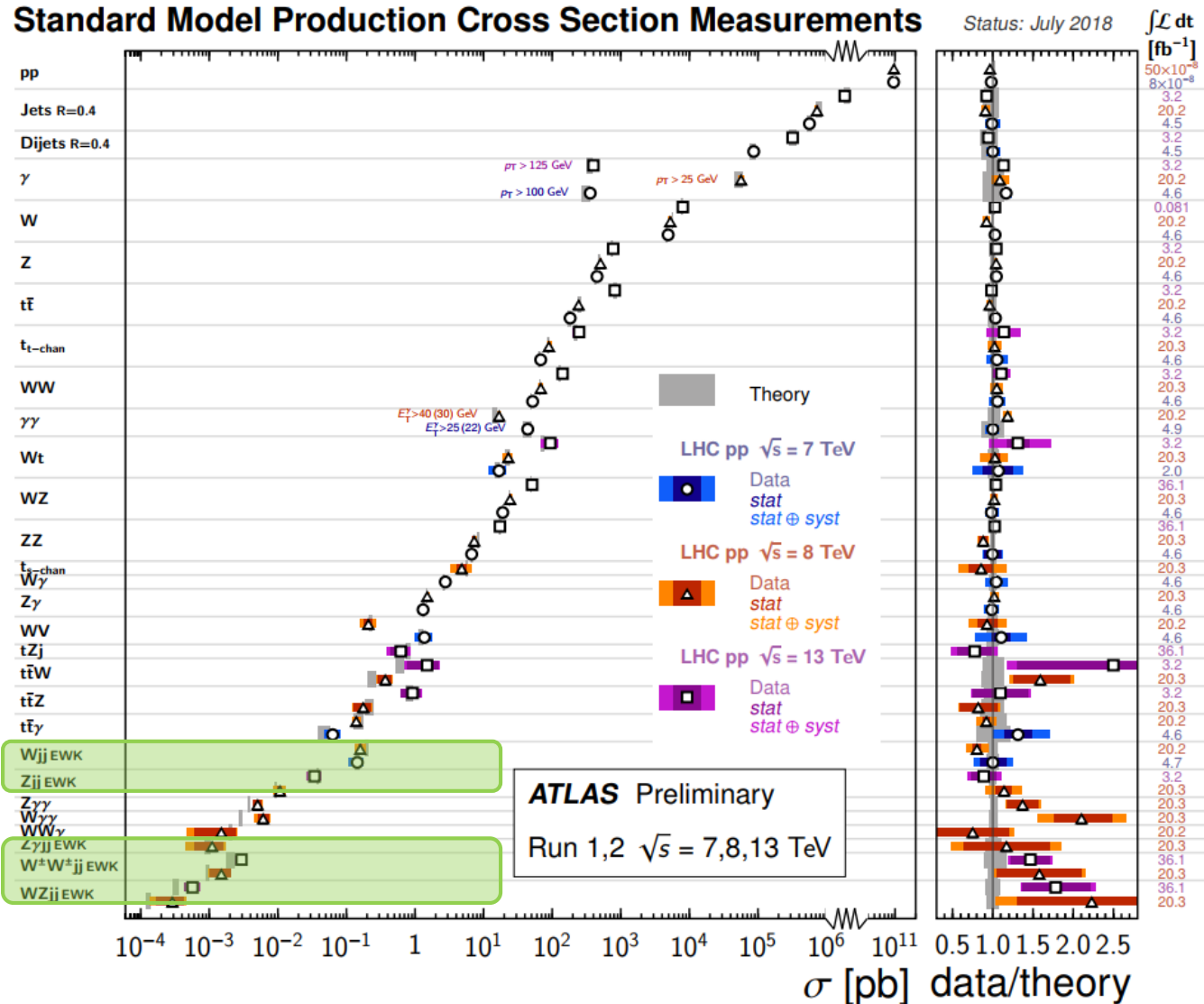➢ No latest result

Zγγ production at 8 TeV

WWW production at 8 TeV

Measurements of rare processes

- Single W/Z bosons

- Diboson production

- Triboson production

- **Rare processes VBS, VBF**

Measurements of rare processes

➤ VBF and VBS : Well measured at 7/8 TeV

- ◦ EW Wjj VBF production at 7 and 8 TeV
  [Eur. Phys. J. C 77 (2017) 474]

- ◦ EW Zjj VBF production at 8 TeV
  [JHEP04(2014)031]

- ◦ Zγ VBS production at 8 TeV
  [JHEP07(2017)107]

- ◦ WW VBS production at 8 TeV
  [Phys. Rev. Lett. 113, 14180]

- ◦ WZ VBS production at 8 TeV
  [Phys. Rev. D 93, 092004 (2016)]

➤ 3 latest ATLAS results at 13 TeV in this talk:
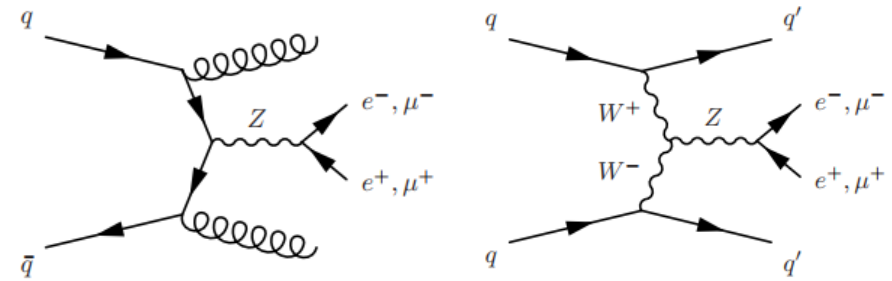- • EW Zjj VBF at 13 TeV
- • WW VBS at 13 TeV
- • WZ VBS at 13 TeV
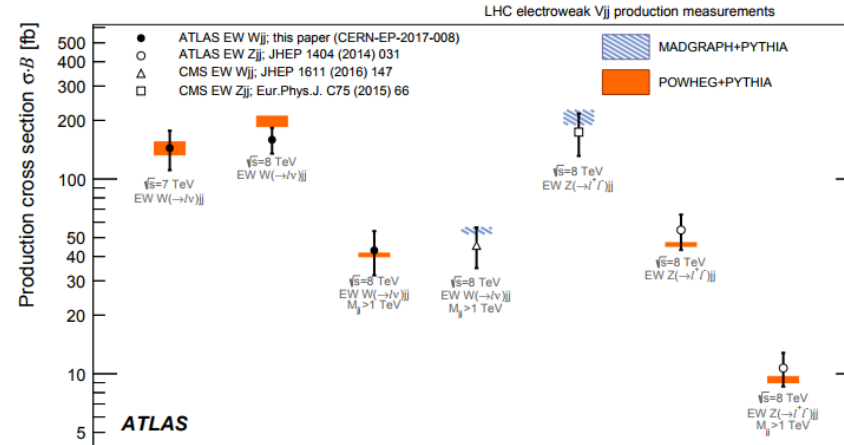
Electroweak Vjj production

Zγ VBS production at 8 TeV
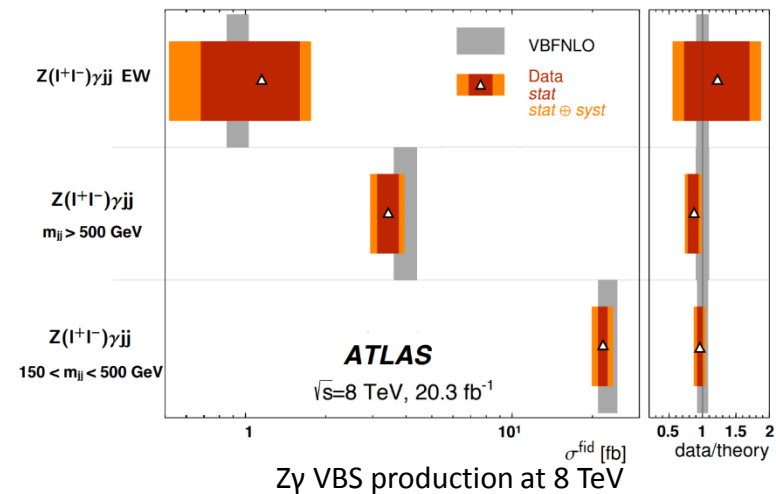
EW Zjj (VBF) at 13 TeV
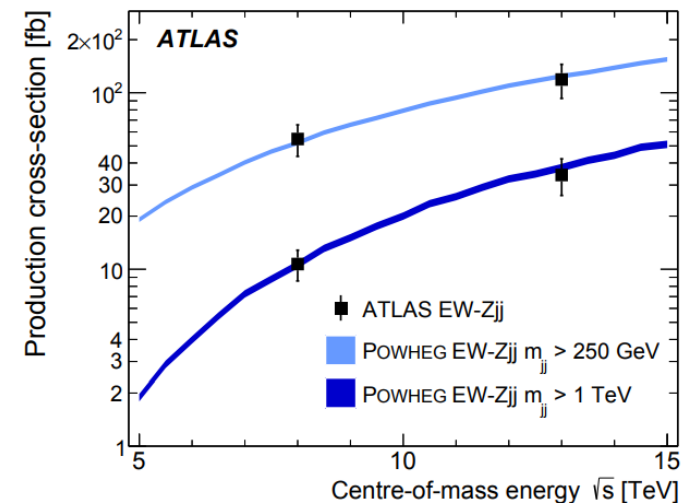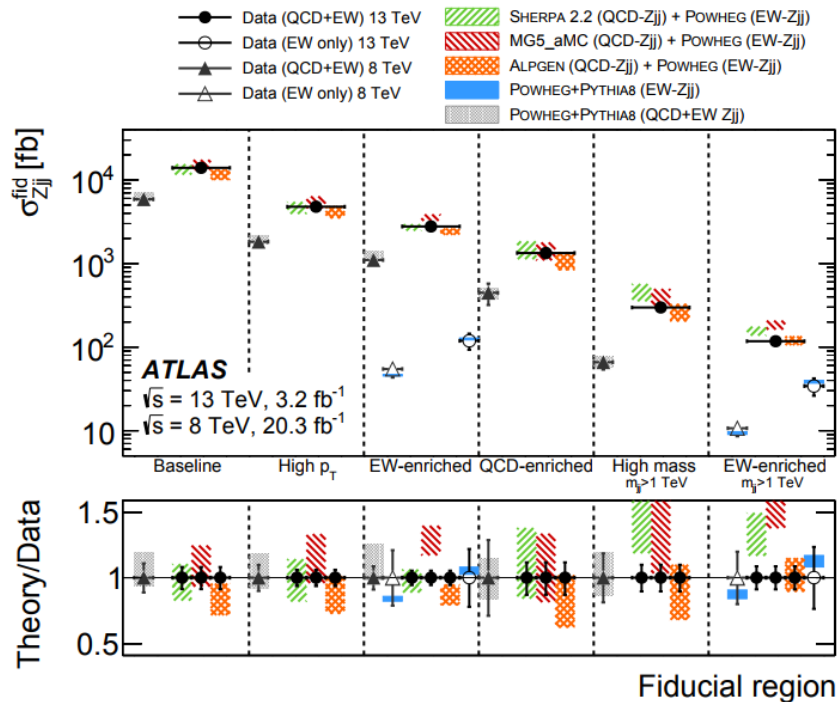
- Select leptonic decay of Z boson
- Major background: diboson, top, multijet, W+jets
- Signal MC: Powheg

➤ Inclusive Zjj fiducial cross sections is measured in 6 fiducial regions

➤ Good Agreement with SM prediction

➤ Results are compared to 8 TeV publication

- A significant rise in cross-section is observed within each fiducial region

- In the EW-enriched region, EW-Zjj cross-sections at 13 TeV are respectively 2.2 and 3.2 times as large as those measured at 8 TeV
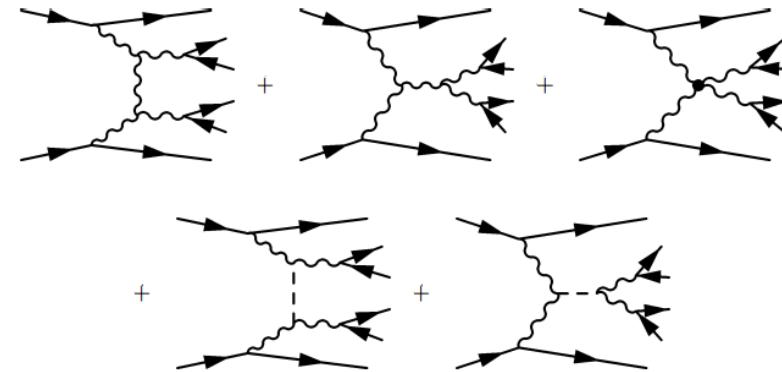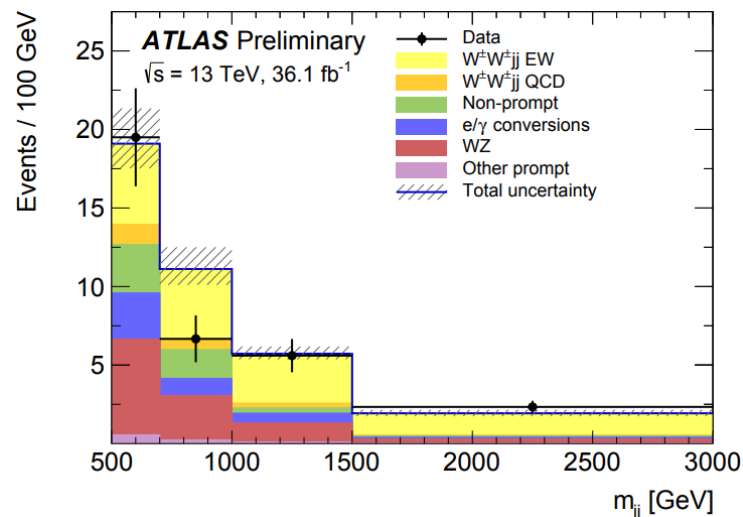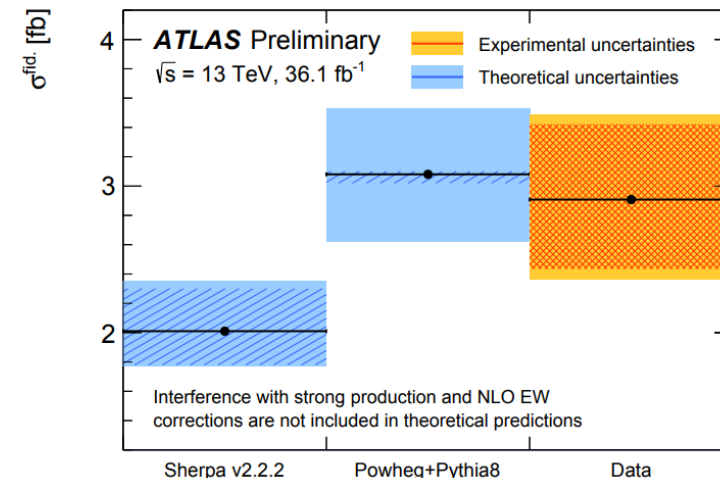
$W^{\pm}W^{\pm}jj$ (VBS) at 13 TeV

- Select leptonic decay of WWjj $\rightarrow$ lvlvjj
- Major background: WZjj, W+jets, top, $W^{\pm}W^{\mp}$
- Signal MC: Powheg

➢ VBS signal region:

- $N_{jet} \geq 2$
- $p_T^{jet} > 65(35)$ GeV
- $M_{jj} > 500$ GeV
- $|\Delta Y_{jj}| > 2$

➢ Signal events are categorized by the lepton flavor and charge into six channels

➢ Observed $W^{\pm}W^{\pm}jj$ production integrated fiducial cross section is

$$\sigma_{\text{meas.}}^{\text{fid.}} = 2.91^{+0.51}_{-0.47}(\text{stat.}) \pm 0.27(\text{syst.}) \text{ fb}$$

➢ The measured fiducial cross section is compared with predicted by Sherpa and Powheg+Pythia8

➢ Observed significance is 6.9σ (4.6σ expected)

WZjj (VBS) at 13 TeV

- Select leptonic decay of WZjj → lvlljj
- Major background: WZjj-QCD, ZZ, ttV, Z+jets
- Signal MC: Sherpa2.2.2
- ➢ VBS signal region:
  - $N_{jet} \geq 2$
  - $p_T^{jet} > 40\ GeV$
  - $M_{jj} > 500$ GeV
  - b-jet Veto
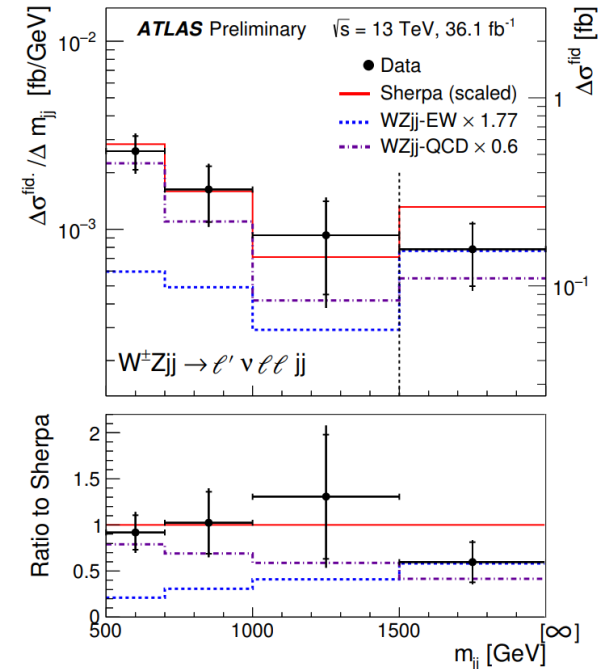- ➢ BDT discriminant based on 15 variables extract VBS signal
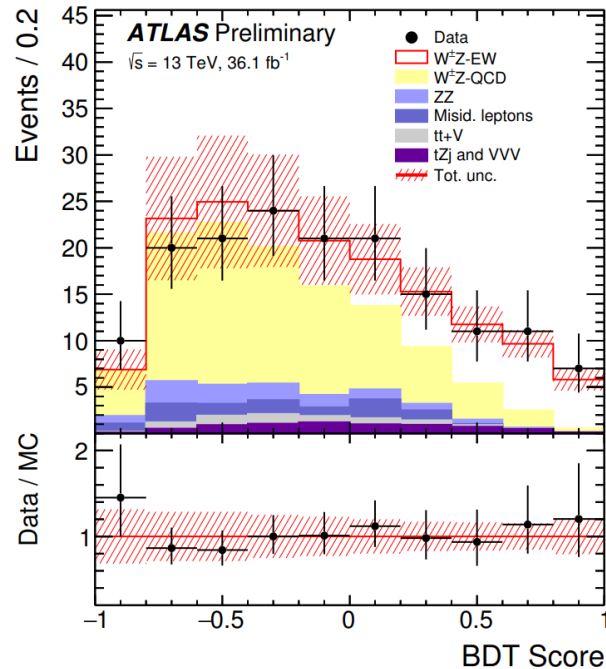
➢ WZjj-EW production integrated fiducial cross section is

$$\sigma_{meas.}^{fid.,EW} = 0.57_{-0.13}^{+0.14}(\text{stat.})_{-0.04}^{+0.05}(\text{syst.})_{-0.03}^{+0.04}(\text{th.})\ \text{fb}$$

$$\sigma_{Sherpa,LO}^{fid.,EW\ th.} = 0.321 \pm 0.002(\text{stat.}) \pm 0.005(\text{PDF})_{-0.023}^{+0.027}(\text{scale})\ \text{fb}$$

➢ Observed significance is 5.6σ (3.3σ expected)

➢ Differential cross-sections is extracted in SR

Summary

➢ The electroweak precision measurements

- 3D Drell-Yan cross sections, tau polarization and $\sin^2\theta_{\text{eff}}^{\text{lep}}$ have been measured with Z/γ* decay. They are in good agreement with SM predictions.

➢ Measurements of diboson production

- ZZ, WZ and Zγ, have been measured with proton-proton collision data at 13TeV. Good agreements with SM predictions are observed from the leptonic decay channels.

➢ The large datasets recorded by the experiments render rare processes accessible

- VBF single Z boson has been measured and resulted in a consistent cross section as SM predictions.
- VBS di-boson process $W^{\pm}Z$ and $W^{\pm}W^{\pm}$ have been observed with >5σ and cross-sections agree with SM predictions

Backup

ATLAS experiment
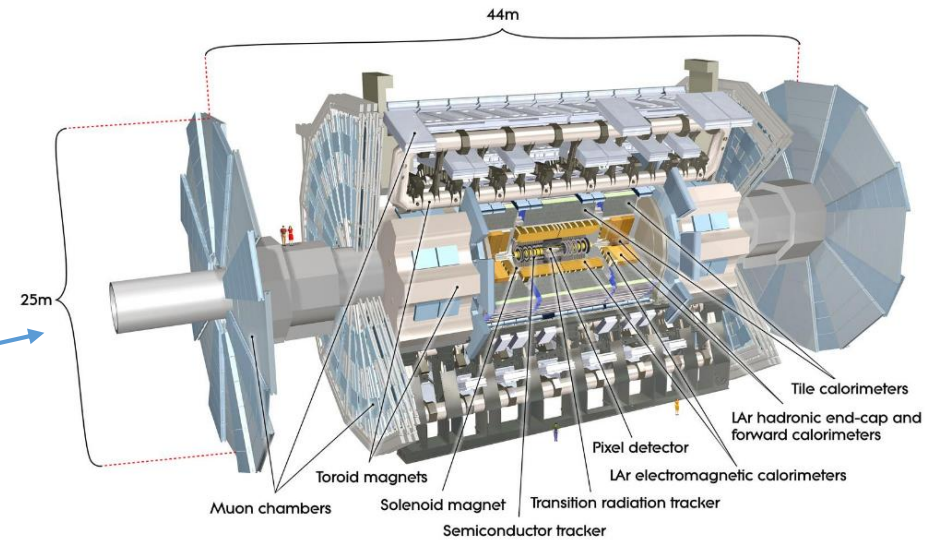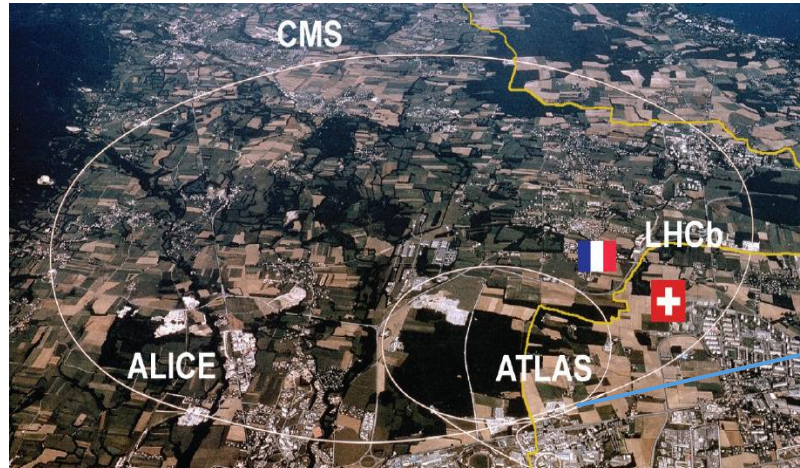


➤ The Large Hadron Collider (LHC) is a 27-kilometre ring with proton-proton collisions at $\sqrt{s}$ = 7/8/13 TeV

➤ ATLAS consists:
- Inner detector($|\eta|$<2.5)
  - charged-particle tracking and momentum measurement
- Electromagnetic calorimeter($|\eta|$<3.2)
  - e/γ trigger, identification and measurement
- Hadronic calorimeter ($|\eta|$<4.9)
  - Jets and MET Trigger , identification and measurement
- Muon spectrometer ($|\eta|$<2.7)
  - Muon trigger, identification and measurement

ATLAS data taking
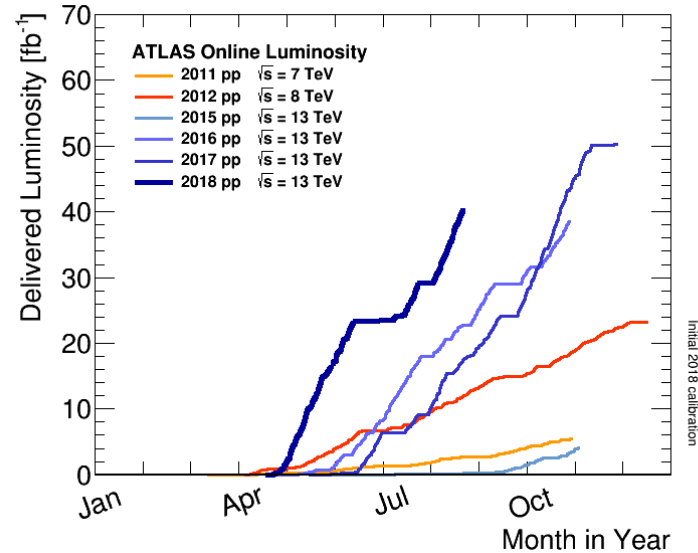
Delivered luminosity versus time for 2011-2018(p-p data only)
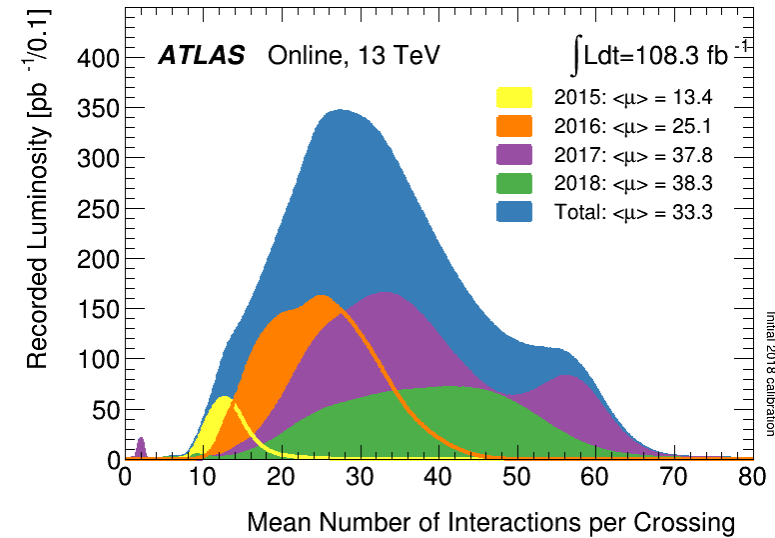
Number of interactions per crossing

	2010-2011	2012	2015	2016	2017	2018 Goal
$\sqrt{s}$	7Tev	8Tev	13Tev	13Tev	13Tev	13 TeV
Good Run Luminosity	4.57 fb^{-1}	20.2 fb^{-1}	3.2 fb^{-1}	32.9 fb^{-1}	44.3 fb^{-1}	60 fb^{-1}