Observation of electroweak *Zjj* production

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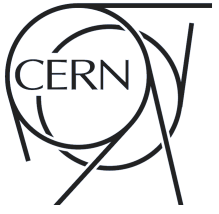


Introduction

- **signal process:**

  EW *Zjj* production via *t*-channel exchange of a vector boson

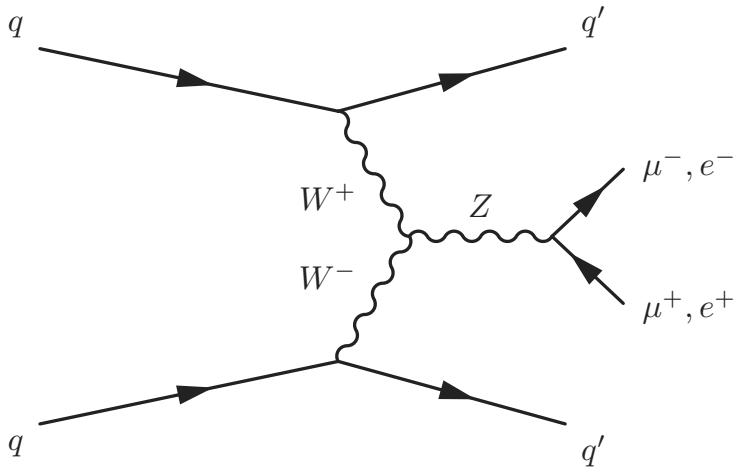
$$q + q \longrightarrow q' + q' + Z$$
$$Z \longrightarrow \ell^+ + \ell^-$$

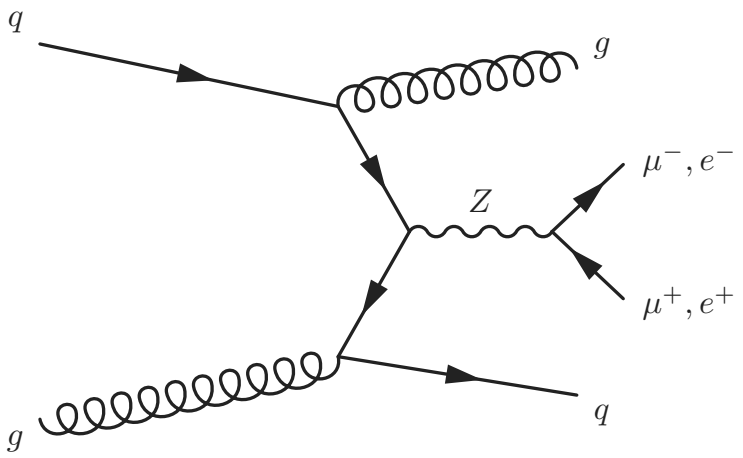
- 7 diagrams in total (cf. backup), including **vector boson fusion** (VBF) and Z-bremsstrahlung diagrams

- **main background:**

  strong *Zjj* production with jets being produced via strong interaction

$$q + g \longrightarrow q + g + Z$$
$$Z \longrightarrow \ell^+ + \ell^-$$



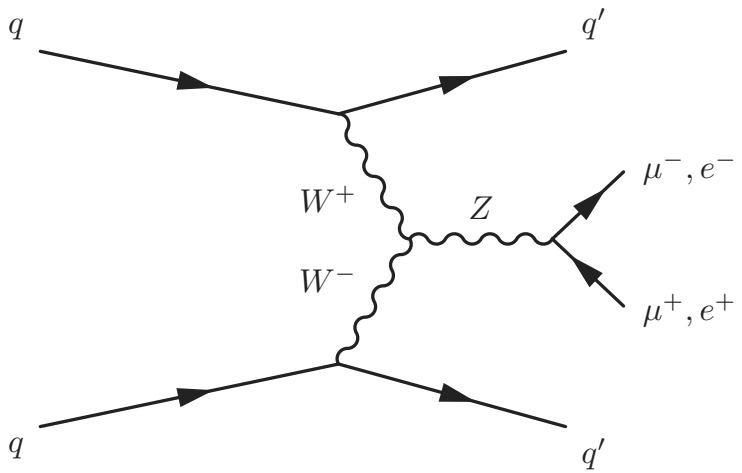


Motivation

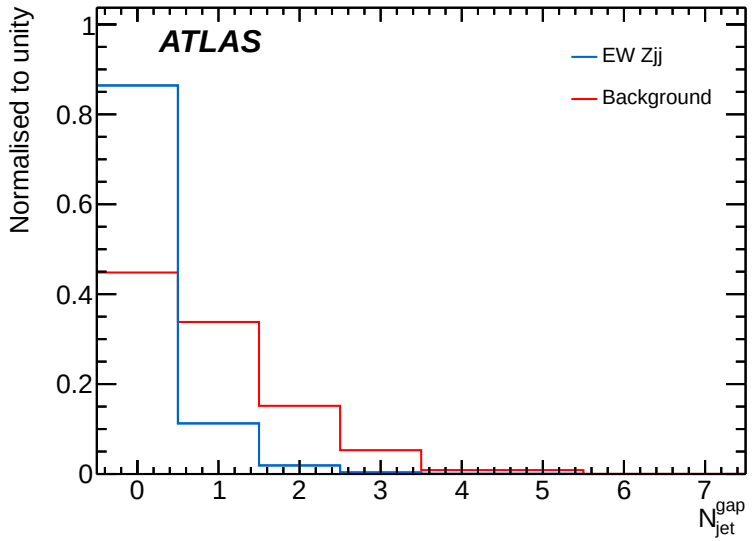
- VBF Z production **similar to VBF production of a Higgs** boson
  - VBF second-largest production mechanism of the Higgs at the LHC
  - significance improved by including the VBF category
  - understanding VBF kinematics important for Higgs precision measurements
- VBF diagram **sensitive to new physics** via WWZ triple gauge coupling
  - understanding VBF-like processes also important because they constitute backgrounds in many new physics searches
- helps validate the Monte Carlo

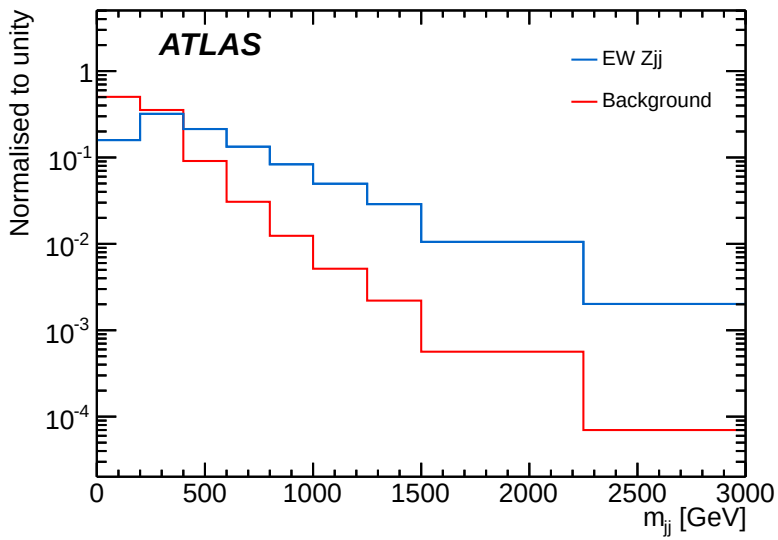
Main signal features

- colourless exchange of vector bosons
- jets tend to be produced at large rapidities with sizeable transverse momentum and together they balance the Z boson



- results in **two forward jets with large dijet invariant mass** and **no additional jets in the rapidity interval** between them





ATLAS Collaboration, arXiv:1401.7610

Strategy and selection

- select events requiring a Z candidate with tight invariant mass cut and at least two high-p_T jets

- use jet multiplicity in rapidity interval between leading two jets to construct signal-enhanced ($N_{\text{jet}}^{\text{gap}} = 0$) and signal-suppressed ($N_{\text{jet}}^{\text{gap}} \geq 1$) regions

- use signal-suppressed control region to **constrain shape of the background model**

- extract electroweak Zjj component in signal-enhanced search region using two-component template **fit to dijet invariant mass spectrum**

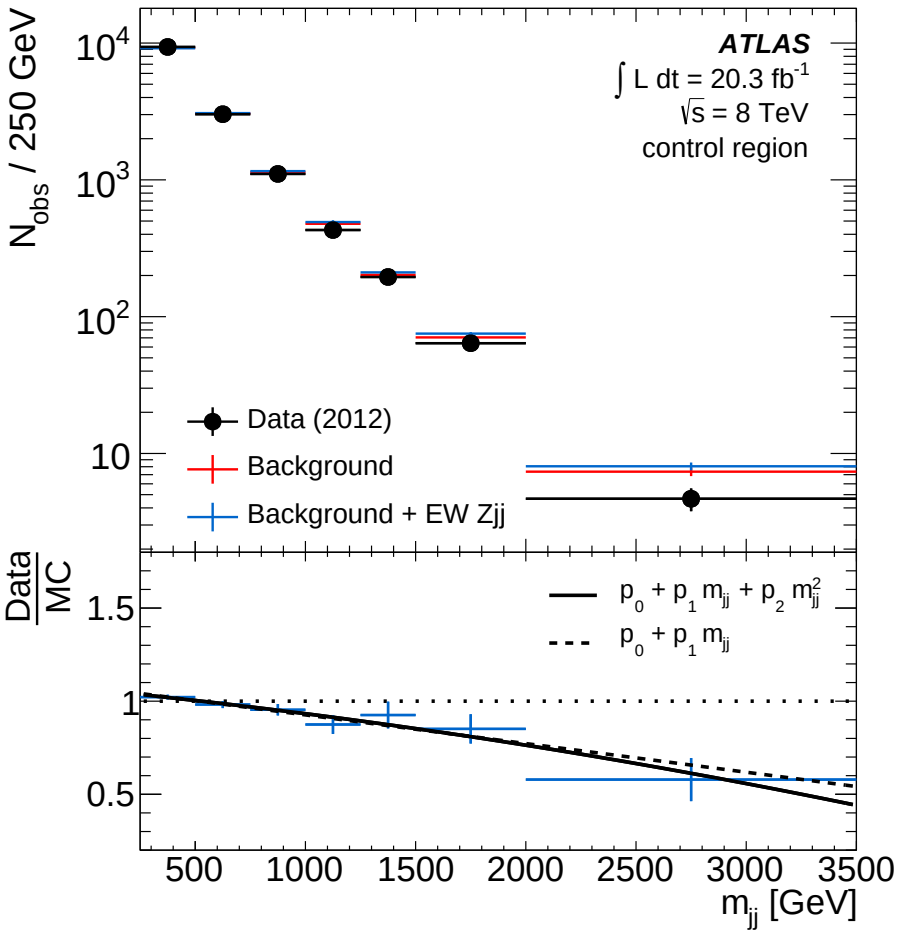
region	yield for N_{EW}
$m_{jj} > 250$ GeV	1657^{+134}_{-132} (fit) ± 40 (MC)
$m_{jj} > 1$ TeV	333^{+27}_{-26} (fit) ± 8 (MC)

- convert signal yields into fiducial cross sections and **correct back to particle level** using a correction factor (C_{EW})

Control region constraint

- fit of data-to-MC ratio in **control region used to constrain shape of background model in search region**
- get strong *Zjj* modelling directly from data
- **constrains systematics** on background model

dijet invariant mass in control region



ATLAS Collaboration, arXiv:1401.7610

Systematic uncertainties

Source	ΔN_{EW}		$\Delta \mathcal{C}_{\mathrm{EW}}$	
	Electrons	Muons	Electrons	Muons
Lepton systematics	—	—	±3.2 %	±2.5 %
Control region statistics	±8.9 %	±11.2 %	—	—
Jet-energy scale	±5.6 %		$^{+2.7}_{-3.4}$ %	
Jet-energy resolution	±0.4 %		±0.8 %	
Pileup jet modelling	±0.3 %		±0.3 %	
Jet-vertex fraction	±1.1 %		$^{+0.4}_{-1.0}$ %	
Signal modelling	±8.9 %		$^{+0.6}_{-1.0}$ %	
Background modelling	±7.5 %		—	
Signal/background interference	±6.2 %		—	
Parton distribution function	$^{+1.5}_{-3.9}$ %		±0.1 %	

EXPERIMENTAL

THEORY

Search region ($m_{jj} > 250$ GeV)

- Measurement:

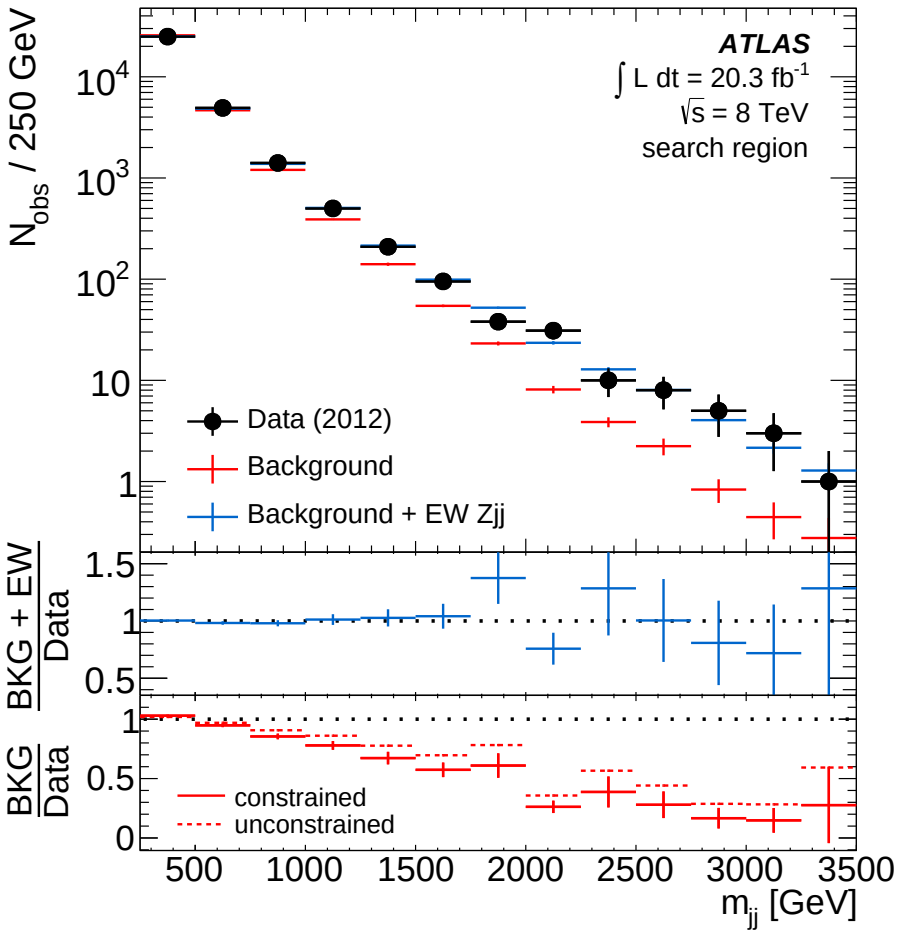
$$54.7 \left\{ \begin{array}{ll} \pm 4.6 & \text{(stats)} \\ {}^{+9.8}_{-10.4} & \text{(syst)} \\ \pm 1.5 & \text{(lumi)} \end{array} \right. \text{fb}$$

- Standard Model prediction:

$$46.1 \left\{ \begin{array}{ll} \pm 0.2 & \text{(stats)} \\ {}^{+0.3}_{-0.2} & \text{(scale)} \\ \pm 0.8 & \text{(PDF)} \\ \pm 0.5 & \text{(model)} \end{array} \right. \text{fb}$$

(using `Powheg`)

dijet invariant mass in search region



ATLAS Collaboration, arXiv:1401.7610

Search region with $m_{jj} > 1$ TeV

- Measurement:

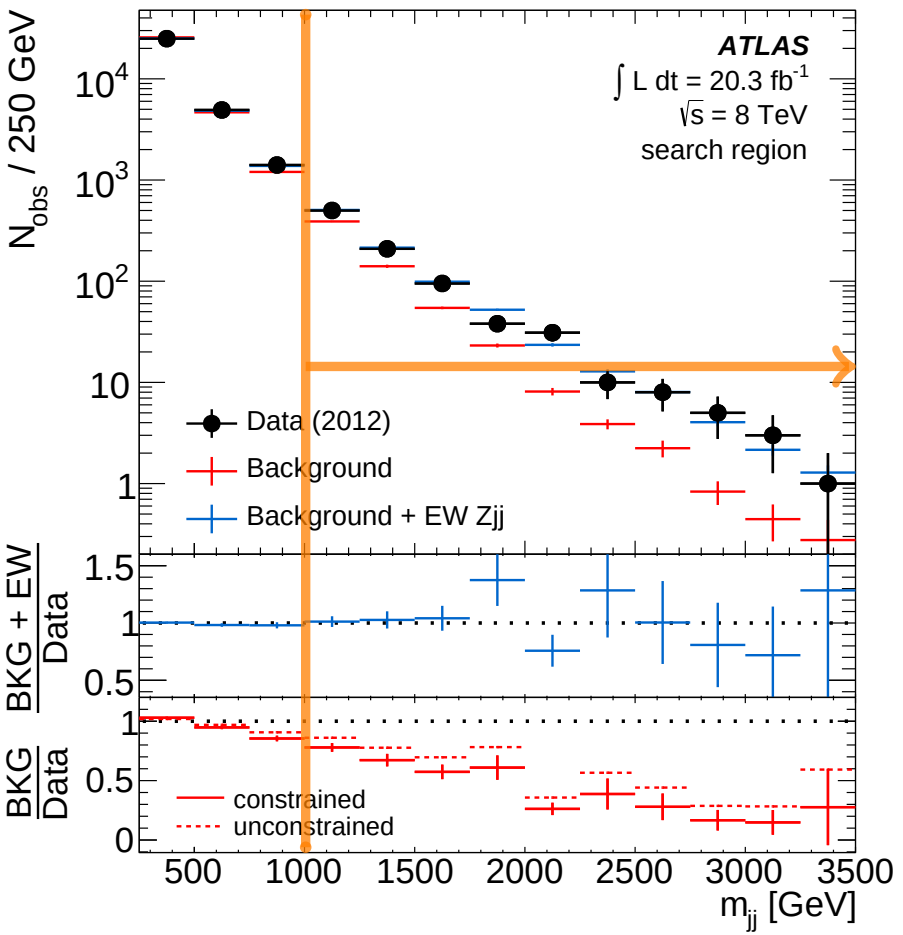
$$10.7 \begin{cases} \pm 0.9 & \text{(stats)} \\ \pm 1.9 & \text{(syst)} \\ \pm 0.3 & \text{(lumi)} \end{cases} \text{fb}$$

- Standard Model prediction:

$$9.38 \begin{cases} \pm 0.05 & \text{(stats)} \\ {}^{+0.15}_{-0.24} & \text{(scale)} \\ \pm 0.24 & \text{(PDF)} \\ \pm 0.09 & \text{(model)} \end{cases} \text{fb}$$

(using `Powheg`)

dijet invariant mass in search region



ATLAS Collaboration, arXiv:1401.7610

Limits on aTGCs

- observation of EW *Zjj* offers completely complementary test of anomalous triple gauge couplings
  - two gauge bosons in VBF diagram enter *WWZ* vertex with space-like momentum ($Q^2 < 0$)
- aTGC limits obtained from counting number of events with $m_{jj} > 1$ TeV in search phase space
- limits presented with and without form factor unitarisation:

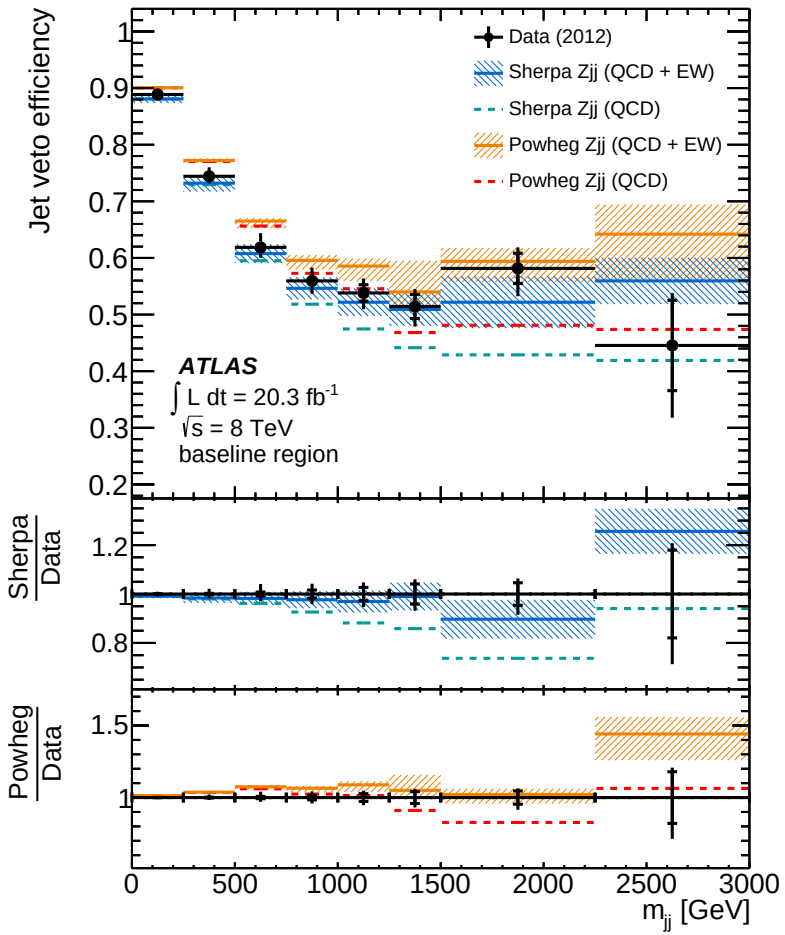
aTGC parameter	$\Lambda = 6$ TeV (obs)	$\Lambda = 6$ TeV (exp)	$\Lambda \longrightarrow \infty$ (obs)	$\Lambda \longrightarrow \infty$ (exp)
$\Delta g_{1,Z}$	$[-0.65, 0.33]$	$[-0.58, 0.27]$	$[-0.50, 0.26]$	$[-0.45, 0.22]$
λ_Z	$[-0.22, 0.19]$	$[-0.19, 0.16]$	$[-0.15, 0.13]$	$[-0.14, 0.11]$

- first ever limits at a hadron collider that use VBF diagram

Summary

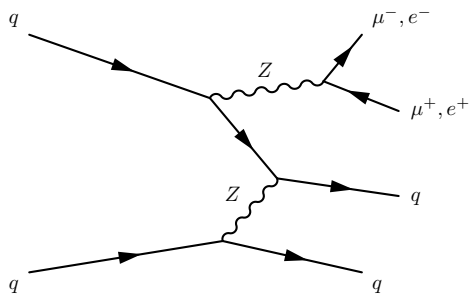
ATLAS Collaboration, *Measurement of the electroweak production of dijets in association with a Z-boson and distributions sensitive to vector boson fusion in proton-proton collisions at* $\sqrt{s} = 8$ *TeV using the ATLAS detector*, accepted by JHEP, arXiv:1401.7610

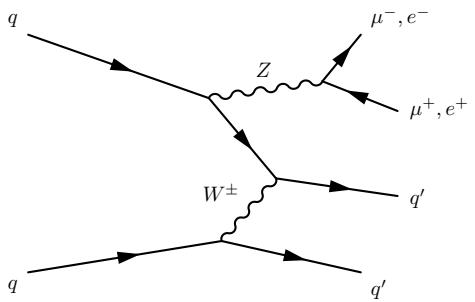
- measurement of electroweak *Zjj* production in two fiducial regions
  - first observation with significance beyond 5σ-level of a process involving a VBF diagram
- measurements in excellent agreement with theoretical predictions
- results also used to set limits on anomalous triple gauge couplings
- measurement of inclusive *Zjj* cross sections and differential distributions in five fiducial regions with varying sensitivity to electroweak component

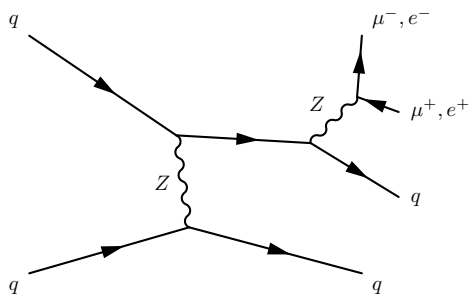


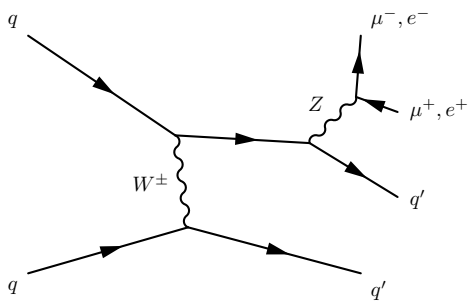
Backup

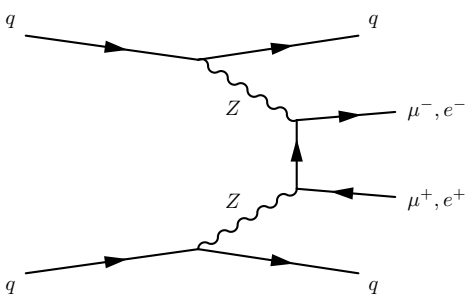
Signal diagrams

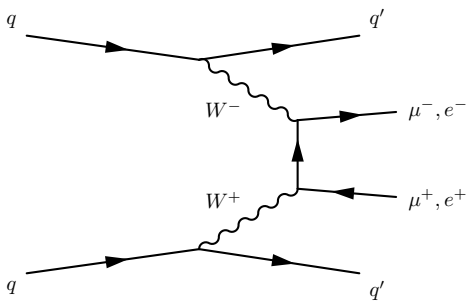


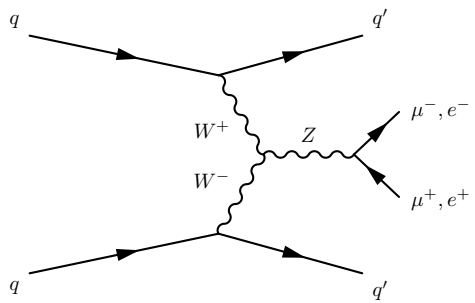




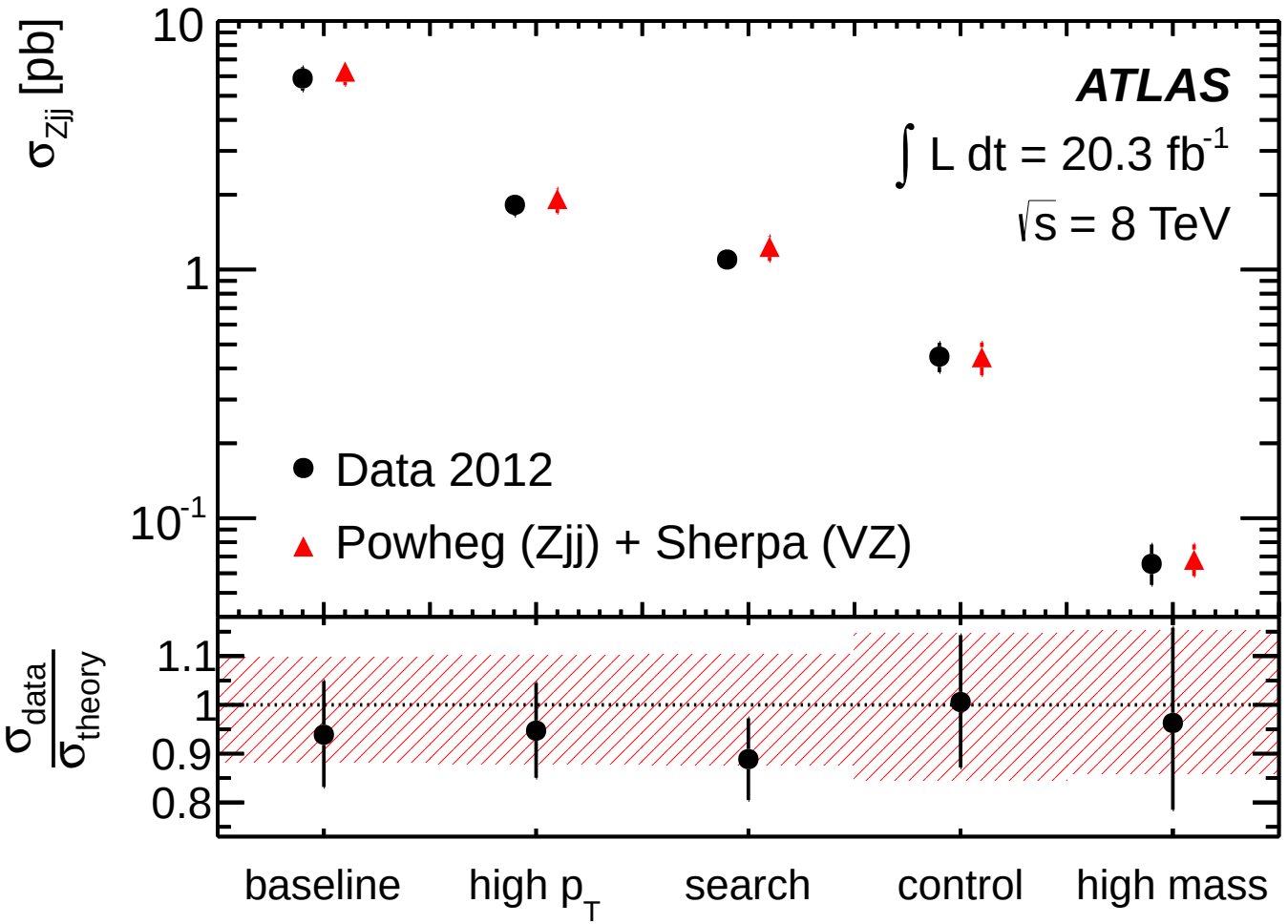








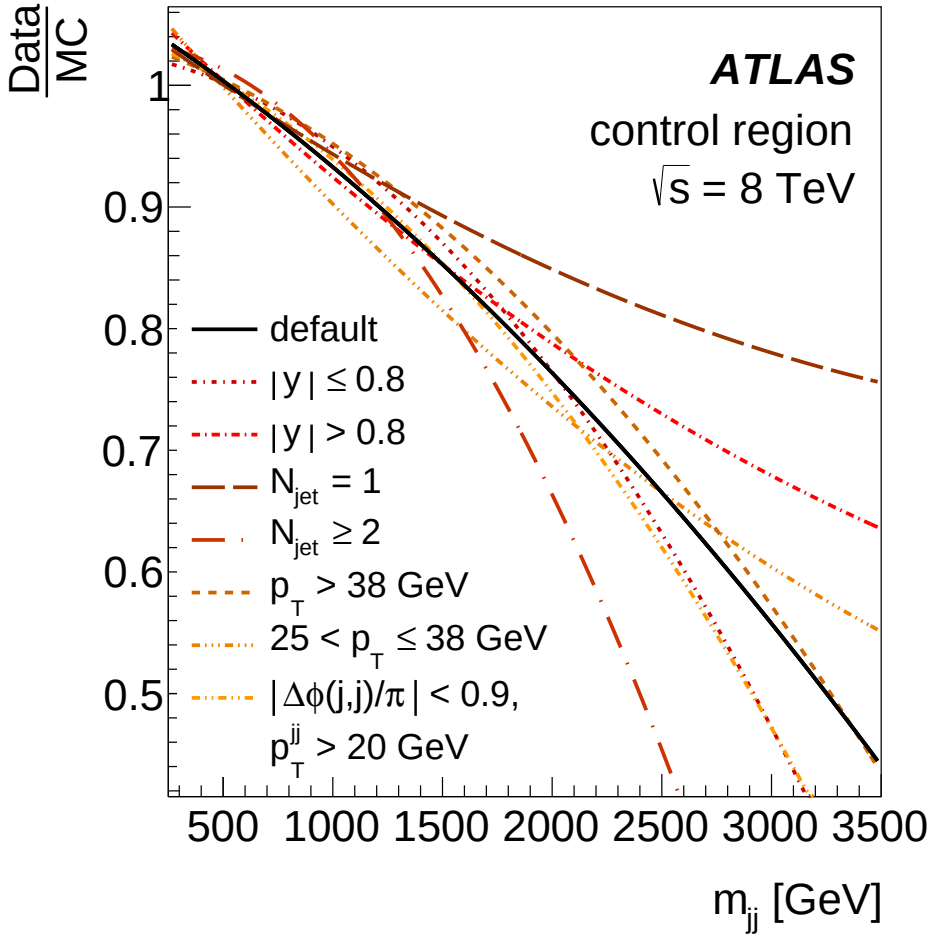
Measurements of inclusive *Zjj* production



ATLAS Collaboration, arXiv/1401.7610

Choice of control region

- nominal control region split into 6 different subregions probing additional jet activity in rapidity interval between leading jets:
  - nominal control region split based on rapidity of in-gap jet
  - nominal control region split based on p_T of in-gap jet
  - nominal control region split based on number of in-gap jets
- MPI-suppressed subregion:
  - nominal control region with dijet $p_T^{jj} > 20\,\text{GeV}$ and $|\Delta\phi(j,j)| < 0.9\pi$



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- **consistent signal yield with maximum 5 % spread** between subregions, i.e. within statistical uncertainty of extrapolation ($\sim$ 10 %)