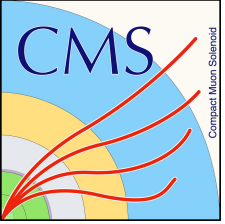

Associated production of a vector boson with light jets

SM@LHC2022

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Introduction

- W and Z bosons are produced at high rate at the LHC in collisions with different center of mass energies (7, 8 and 13 TeV)

- Processes involving production of Z or W boson in association with jets are an important part of the LHC physics program:
  - ⇒ provide fundamental tests of quantum chromodynamics (QCD)
  - ⇒ important for understanding and modelling QCD interactions
  - ⇒ essential to improve theoretical predictions and MC generator techniques
  - ⇒ constrain the parton distribution functions (PDFs)
  - ⇒ important background to many Standard Model processes as well as to searches for physics beyond the SM

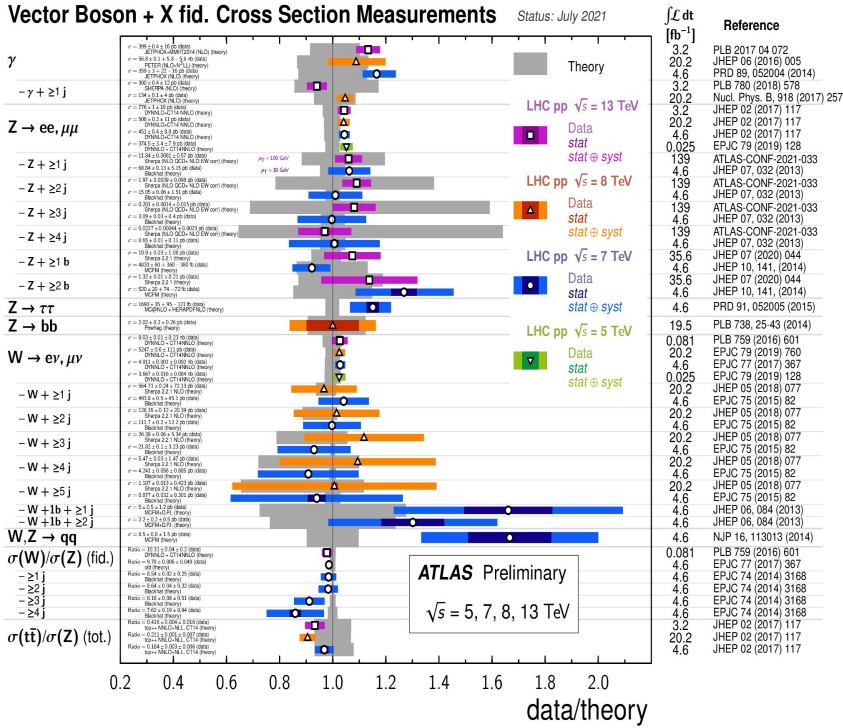
- W and Z bosons are reconstructed via leptonic final states that are the cleanest final states experimentally

  ➢ **The most recent V + jets results from ATLAS, CMS and LHCb collaboration are presented in this talk**

Analyses overview

In today's talk:

- ✓ Measurements of the production cross section of a *Z* boson in association with high transverse momentum jets in *pp* collisions at √s = 13 TeV with the **ATLAS** detector
- ✓ Azimuthal correlations in Z+jets events at 13 TeV (**CMS**)
- ✓ Measurement of multi-differential cross sections for the production of a Z boson in association with jets in proton-proton collisions at √s = 13 TeV (**CMS**)
- ✓ Measurement of charged hadron production in Z-tagged jets in proton-proton collisions at √s = 8 TeV (**LHCb**)
- ✓ Measurement of forward W and Z boson production in association with jets in proton-proton collisions at √s =8TeV (**LHCb**)
- ✓ Determination of the parton distribution functions of the proton from **ATLAS** measurements of differential $W^{\pm}$ and Z boson production in association with jets



Full list of analyses:

⇒ **ATLAS** : https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults

⇒ **CMS** : https://cms-results.web.cern.ch/cms-results/public-results/publica6ons/SMP/index.html

⇒ **LHCb** : https://lhcbproject.web.cern.ch/lhcbproject/Publica6ons/LHCbProjectPublic/Summary_QEE.html

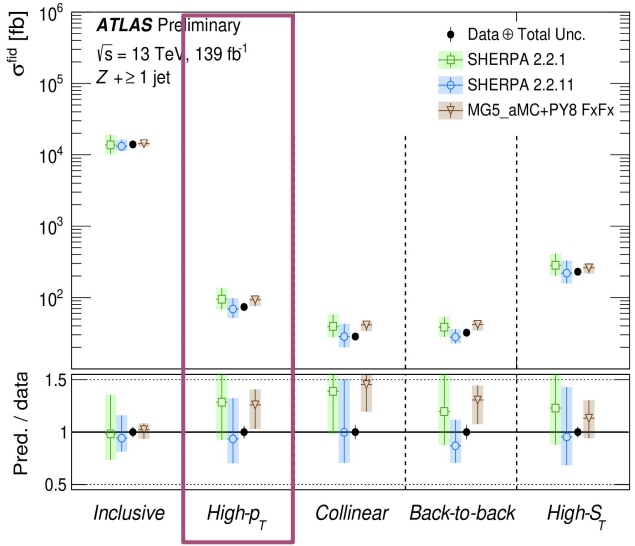
Collinear Z + jets

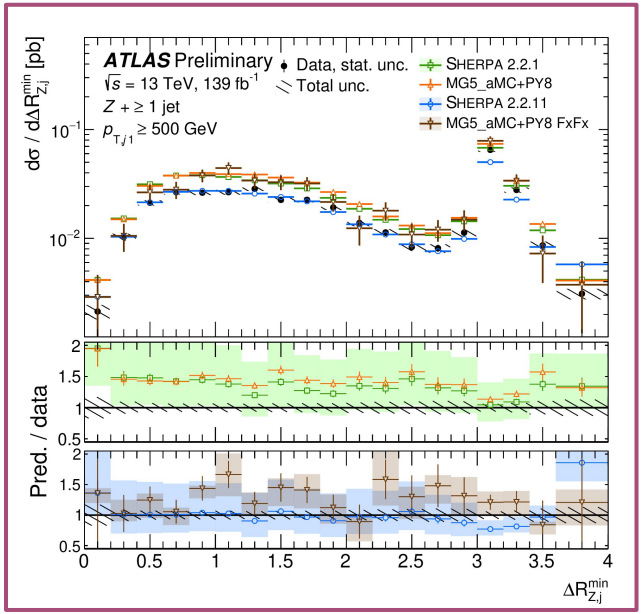
- Measurements of the cross section of a Z boson produced in association with at least one high p_T jet
- Results include **electron and muon channels combined**

13 TeV, 139 fb^{-1}

ATLAS-CONF-2021-033

CMS: JHEP 05 (2021) 285





- ➢ SHERPA 2.2.11 and **MG5_aMC+PY8 FxFx** show **improved modelling** in collinear and high p_T regions
- ➢ **MG5_aMC+PY8** and SHERPA 2.2.1 overestimate the cross section for large jet p_T and large S_T

SHERPA versions differences:
- addition of a 5th parton at LO in the ME
- the addition of NLO virtual EW corrections
- different treatment of unordered histories in the parton shower

- ✓ Inclusive: jet p_T > 100 GeV, |y| < 2.5
- ✓ High p_T: lead jet p_T > 500 GeV
- ✓ High scalar sum p_T of jets: S_T > 600 GeV

The collinear and the back-to-back events studied

collinear back-to-back

*Results are unfolded to particle-level

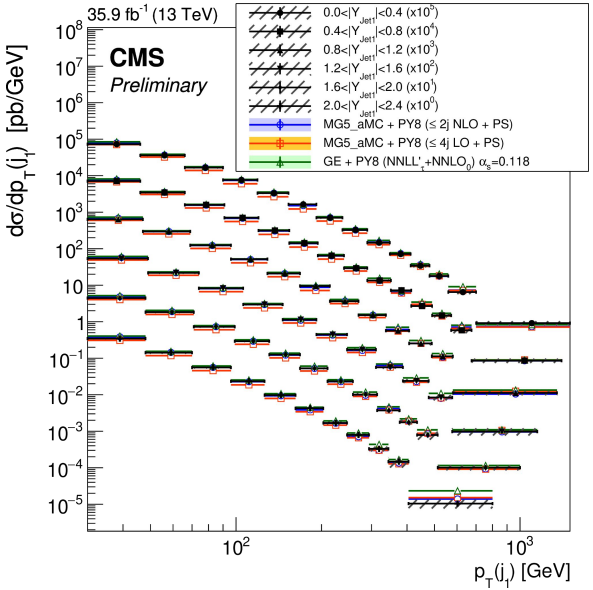
Z + jets differential measurements

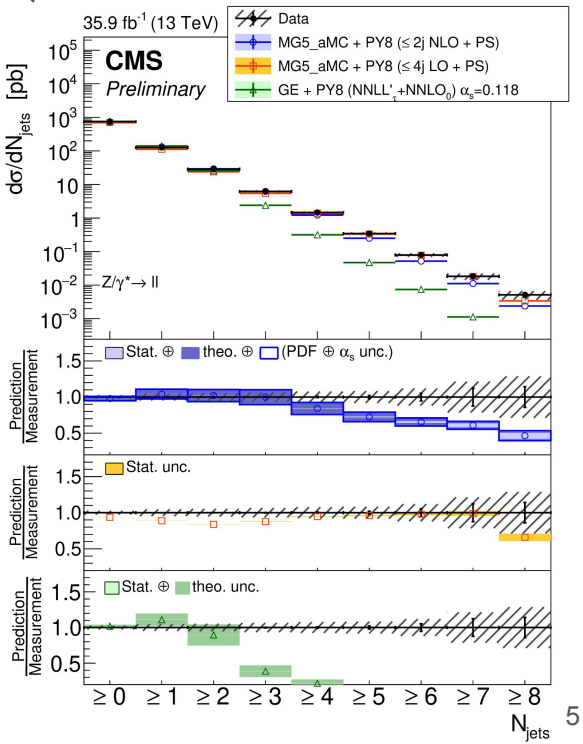
13 TeV, 35.9 fb^{-1}

CMS-PAS-SMP-19-009

- Measurement of differential cross sections as a function of:
  - double differential p_T and |y| of Z and jets
  - exclusive and inclusive jet multiplicities (up to 8 jets)
  - jet p_T and |y| of 5 jets
  - dijet invariant mass.
- Results include **electron and muon channels combined**

- ➢ Measured differential cross sections are within the experimental and theoretical uncertainties of the expectations from theory
- ➢ Deviations are observed for jet multiplicities higher than 3
- ➢ The GENEVA generator – steeper spectrum, because of the lack of hard jets at ME level beyond two





Z + jets azimuthal correlations

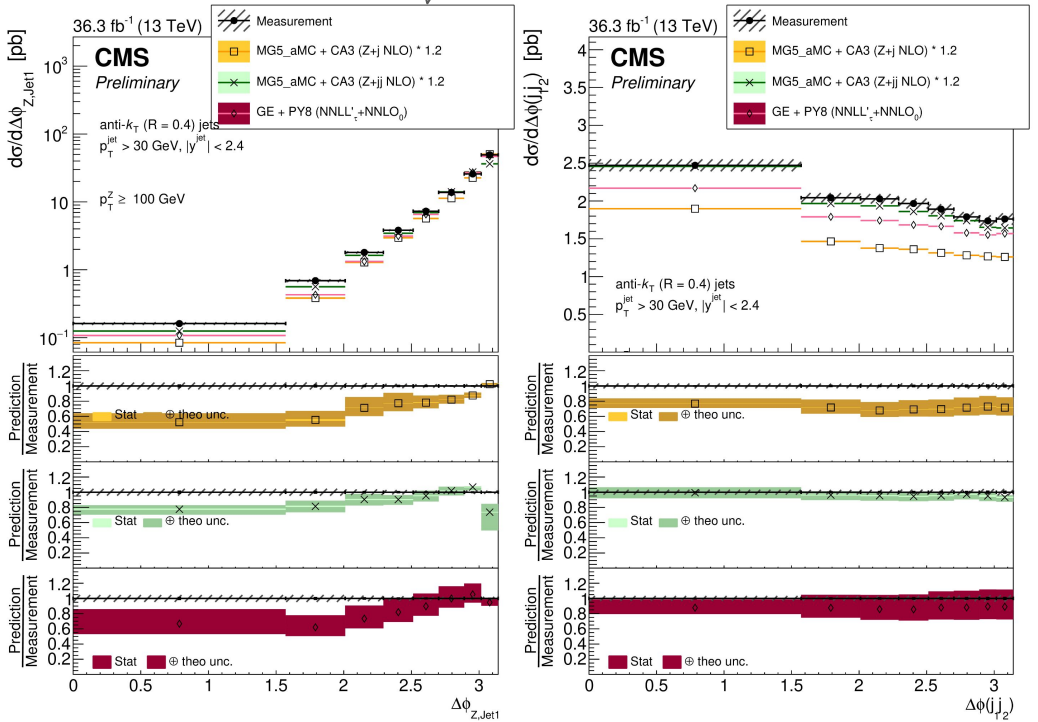
13 TeV, 35.9 fb^{-1}

CMS-PAS-SMP-21-003

- Measurement of the multiplicity of jets, azimuthal correlation between the Z boson and the leading jet, and the correlation between the two leading jets
- Results include **electron and muon channel combined**

Measurement performed in different Z p_T regions:

- ✓ p_T (Z) < 10 GeV
- ✓ 30 < p_T (Z) < 50 GeV
- ✓ p_T (Z) > 100 GeV



➢ The **best description** is from **GENEVA** NNLO
  - matrix elements at NNLO for Z production
  - NNLL' resummation
  - parton shower and MPI from PYTHIA8

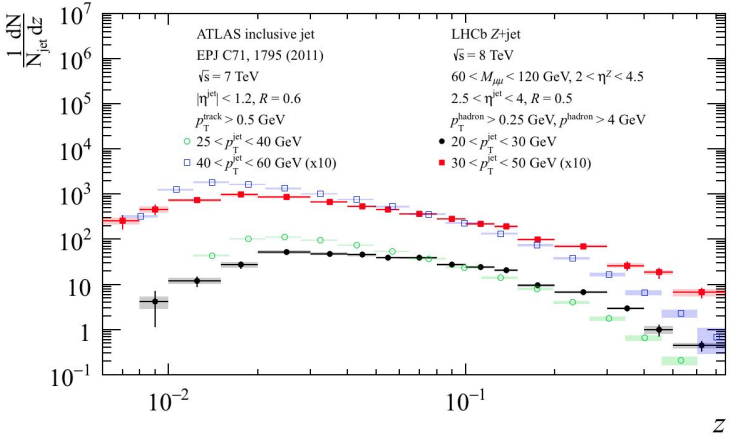
➢ **MG5_AMC+CASCADE3 (Z ≤ 3j LO)** using parton branching -TMD parton densities and parton shower with merging of jet multiplicities - **good agreement** in the regions where MPI is negligible

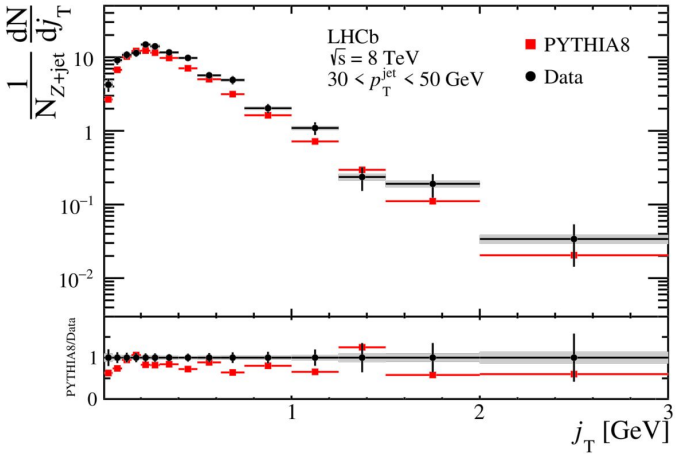
Charged hadrons in forward Z + jets

8 TeV

Phys. Rev. Lett. 123, 232001

- Measurements of charged hadrons in jets recoiling against a Z boson
- First measurements of jet hadronization forward rapidities
- The longitudinal momentum fraction, momentum transverse to the jet axis, and radial profile of the charged hadrons are measured with respect to the jet axis
- Forward measurements compared to inclusive jet measurements at central rapidity from ATLAS - differences between light-quark and gluon fragmentation





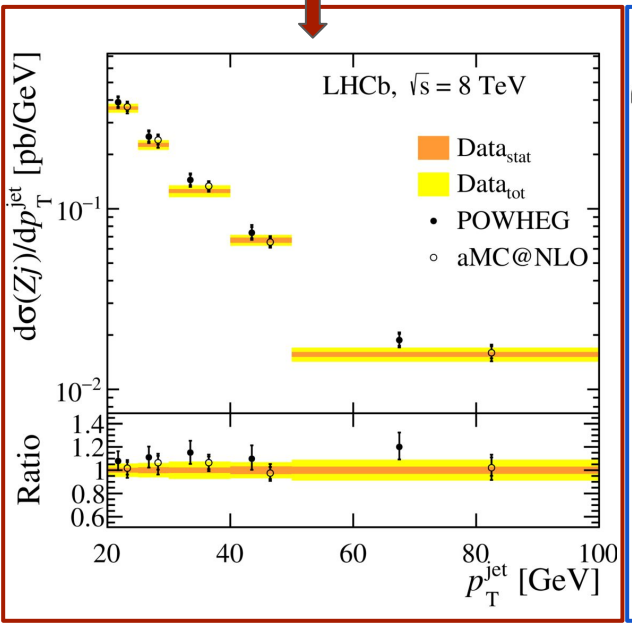
- Light quark-dominated jets recoiling against a Z boson at forward rapidity are more collimated in both z and r
- **PYTHIA8** underestimates the number of charged hadrons

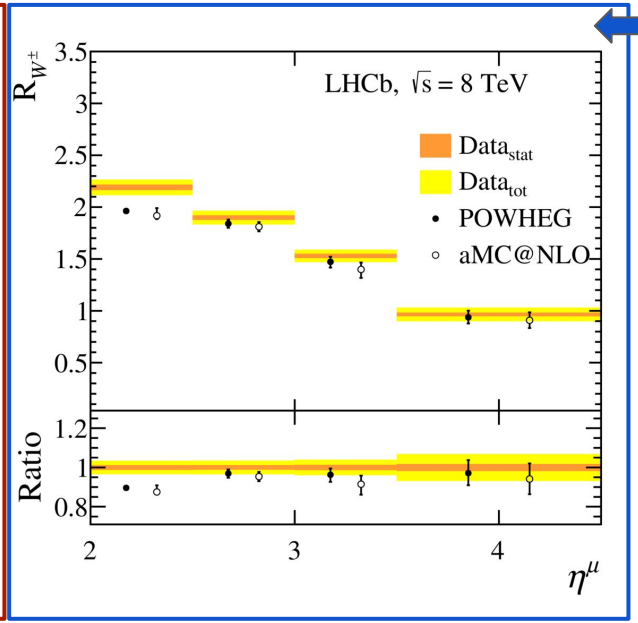
V + jets at forward rapidities

- Measurements of the forward W and Z boson cross sections in association with jets
- Differential cross sections measured for:
  - $W \rightarrow \mu\nu_\mu$: as a function of $p_{T,jet}$, η_{jet}, and η_μ
  - **$Z \rightarrow \mu\mu$: as a function of $p_{T,jet}$**, η_{jet}, y_Z , and $|\Delta\varphi|_{Z,j}$

8 TeV, 1.98 fb^{-1}

LHCb-PAPER-2016-011





Ratio measurements:

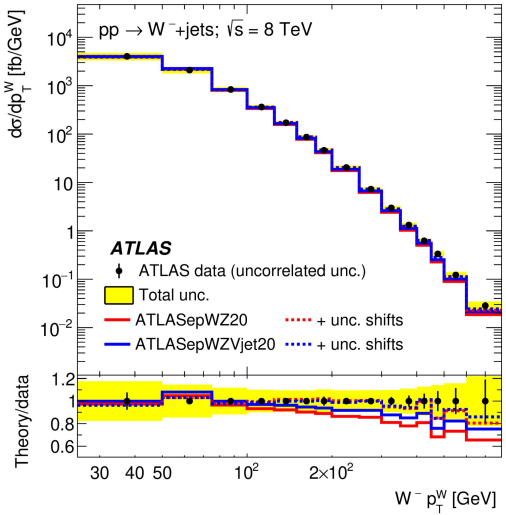
- ✓ **The ratio of the W^+ to the W^-**
- ✓ The ratio of the W cross sections to the Z cross section
- ✓ The charge asymmetry of W production as a function of η_μ

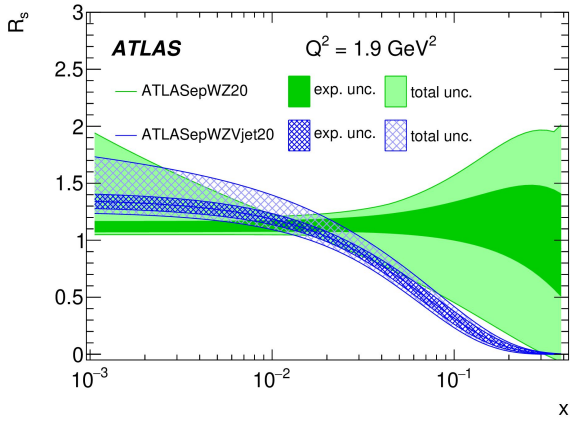
- Overall **good agreement** between the data and the **POWHEG** and **aMC@NLO** predictions
- Slightly larger ratio and asymmetry in data particularly in the first bin of η_μ

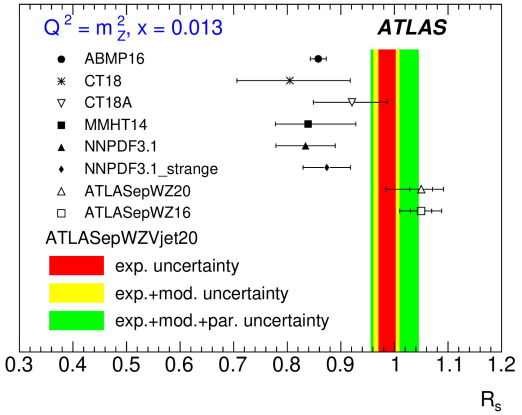
Parton distribution functions from V + jets

JHEP 07 (2021) 223

- Impact of ATLAS measurements of vector boson production in association with at least one jet on the parton distribution functions of the proton
- New set of proton parton distribution functions - **ATLASepWZVjet20**
- NNLO analysis using:
  - Hera data
  - ATLAS W/Z@7TeV
  - ATLAS W/Z+jets@8TeV







- **ATLASepWZVjet20** is similar to the **ATLASepWZ16** for the up quarks and gluon
- For the down and strange sea-quark distributions - **significantly smaller experimental and parameterisation uncertainties** at high Bjorken x

Summary

- Wide range of V + jets results from **ATLAS**, **CMS** and **LHCb** presented
- Measurements are compared with different theoretical predictions up to NNLO precision with different matrix element and parton shower models
  - → overall good agreement is observed for several angular and kinematical observables
- Studies of V + jets provided valuable inputs for improving the existing constraints on the proton PDFs
- LHCEW V + Jets group - working on common strategies for the future of this kind of measurement

Plenty of results still coming from Run 2 data!