Measurements of vector boson plus jets from ATLAS

Yoichi Ninomiya
on behalf of the ATLAS Collaboration

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This talk covers:

- W+jets
- Z+jets
- R-jets
- W+b
- Z+b(b)
- W+c/D
Introduction

- Motivation
  - important tests of pQCD and PDFs
  - important background for many physics

- Progress in theory
  - NLO matrix elements up to 5 jets
  - NLO pQCD samples
    - V+b 4FNS+5FNS, Multileg V+b ME+PS with 4FNS and 5FNS
  - NLO+PS merging samples
    - V+1jets, V+2jets, NLO V+bb+PS
W+jets

- Measure out to 1 TeV, multiplicities up to 7 jets
- Main backgrounds
  - multijets: low multiplicity
  - top: high multiplicity
- Systematics sources
  - dominated by JES, top
- Cross sections as a function of
  - jet multiplicity
  - jet $p_T$, rapidity
  - $H_T$ (scalar sum $p_T$ of all particles)
  - $S_T$ (scalar sum $p_T$ of all jets)
  - $\Delta \phi(j,j)$, $\Delta y(j,j)$, $\Delta R(j,j)$, $M(j,j)$
W+jets

- The leading jet $p_T$ distribution for the case of $W+\geq 1$ jet
- Comparisons from:
  - BlackHat+SHERPA (NLO), LoopSim (approximate NNLO)
  - ALPGEN, SHERPA, ME+PS@NLO (SHERPA NLO)

under estimate the data at large jet $p_T$
reasonable agreement at large jet $p_T$
**W+jets**

- $H_T$ is the scalar $p_T$ sum of the lepton and the jets
  - measure total activity in the event

- The SHERPA predictions tend to be above the data at high $H_T$
W+jets

- The angular separation tests jet production

- BlackHat+SHERPA is in good agreement with data
Z+jets

- Background smaller than W+jets
  - but less reach due to lower cross section

- NLO prediction is consistent with data

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R-jets

- The cross section ratio of W+jets to Z+jets production
- Complementary test of pQCD compared to Z+jets or W+jets
  - cancel systematics and effects from non-perturbative processes
- Measured as a function of many variables
  - $N_{\text{jets}}$ (up to 4 jets)
  - jet $p_T$, rapidity
  - $S_T$ (scalar sum of jet $p_T$)
  - $\Delta R(j,j)$, $\Delta \phi(j,j)$, $M(j,j)$
The theoretical predictions describe the data fairly well.
W+b

- Irreducible background for WH with $H \rightarrow b\bar{b}$
- Several processes contribute to W+b production

Gluon splitting

b-quark in initial state

Double Parton Interaction (DPI)

- Required exactly 1 b-tagged jet
  - W+b (“1 jet”)  
  - W+b+jet (“2 jet”)  
- Flavour tagging based on tracks
  - impact parameter, secondary vertex
MCFM & Powheg applied correction factor for
- non-perturbative effects: 4% (1 jet) and 8% (2 jet)
- DPI: 1 pb (1 jet) and 0.3 pb (2 jet) → ~25% of total cross section

Theory tends to underestimate the data
Z+b(b)

- Irreducible background for $ZH$ with $H \rightarrow b\bar{b}$
- Use same b-tagging algorithm as $W+b$

MCFM predictions agree with the data within the uncertainties.

$Z+b$ is good in 5FNS, while $Z+bb$ is good in 4FNS.
Z+b(b)

- Reasonable descriptions of the data within the uncertainties for Z rapidity
- Low $\Delta R(b,b)$ shows some disagreement, possible a sign of gluon splitting contribution
W+c/D

- Sensitive to strange PDF at x~0.01
- SU(3) flavour symmetry (symmetric light quark sea)
  - broken by the strange quark mass?
  - depends on x?
- c quark tagging method
  - soft muon tagging (semi-leptonic decay to muon)
  - reconstruct charmed hadron
- OS - SS subtraction
  - use charge correlation between W and c to reduce W+c\bar{c} contribution
W+c

- Comparison with aMC@NLO with various PDF sets

The shapes are in good agreement
Decay channels for D meson

- $D^+ \to K\pi\pi$, $D^* \to D^0\pi$ with $D^0 \to K\pi$, $D^0 \to K\pi\pi^0$, $D^0 \to K\pi\pi\pi$

\[ \Delta m = m(D^*) - m(D^0) \text{ [MeV]} \]

\[ \int \text{ATLAS} \]

Ldt = 4.6 fb⁻¹

$\sqrt{s} = 7 \text{ TeV}$

- Data
- Fit
- Signal
- Background

\[ \int \text{ATLAS} \]

Ldt = 4.6 fb⁻¹

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WD(*)

\[ \sigma_{\text{fid}}^{\text{OS-SS}}(W^+D^{(*)}) / \sigma_{\text{fid}}^{\text{OS-SS}}(WD^{(*)}) \]

Data

0.92 ± 0.05 ± 0.01

- aMC@NLO
- CT10
- MSTW2008
- NNPDF2.3
- HERAPDF1.5
- ATLAS-epWZ12
- NNPDF2.3coll

$\sigma(W^+D^{(*)}) / \sigma(W^*D^{(*)})$ can probe $s/\bar{s}$ symmetry, currently compatible with all PDFs

- ratio < 1 because of contribution by d-valence
Determine strange suppression $r_s$ using HERAPDF1.5 set, best fit value:

$$r_s = 0.5(s + \bar{s})/\bar{d} = f_s/(1 - f_s) = 0.96^{+0.16+0.21}_{-0.18-0.24}$$

ATLAS Wc-jet/WD(*) data favor a symmetric light-quark sea in agreement with inclusive W, Z fit (ATLAS-epWZ12)
Conclusion

- $W/Z + \text{jets}$ processes constitute important tests of pQCD with light and heavy flavour quark
- These processes are also important background for many physics
- Theoretical predictions are advancing greatly
  - in general good agreement with the data
  - heavy flavour matching and modeling is a hot topic
  - ATLAS $W+c$ data supports symmetric light-quark sea