V+Jet Covariance Matrices at LHCb

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on behalf of the LHCb collaboration

WG1 Meeting - QCD

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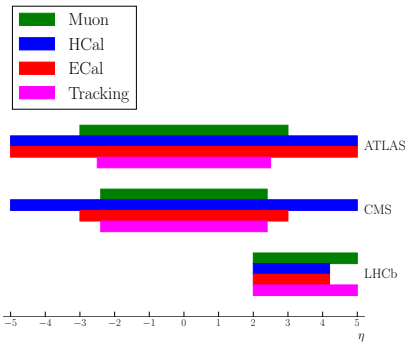
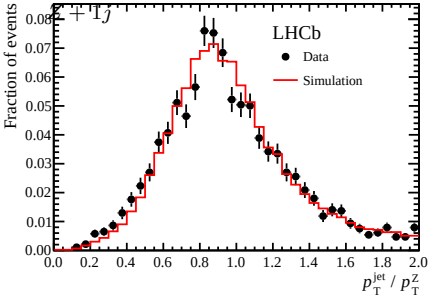
introduction



- LHCb provides complementary coverage to ATLAS/CMS for V+jet measurements
  - full instrumented in the forward region
- unique ability to tag heavy flavour jets in the forward region
- have published three measurements of vector boson + jet production in Run 1
  1. Z+jet at 7 TeV
  2. W/Z+jet at 8 TeV
  3. $Z + b$
  4. $Z + D$ at 7 TeV
  5. $W + (b, c)$ jets at 7 and 8 TeV
- will briefly discuss measurements 1), 2) and 5) with a focus on the systematic uncertainties / covariance matrices

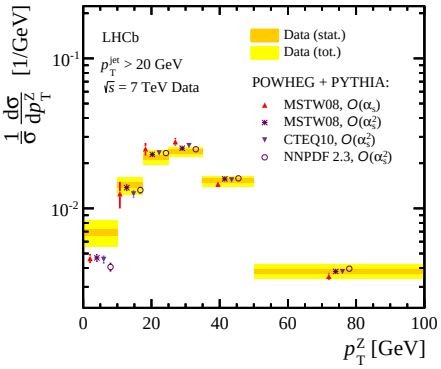
Z+jet at 7 TeV

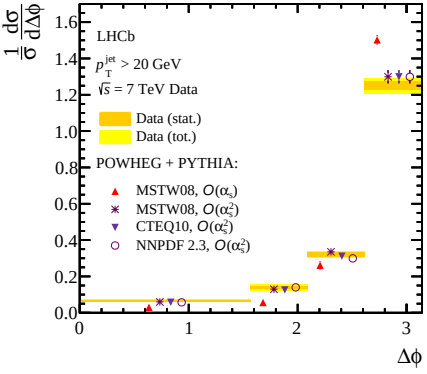
- measurement of Z production in association with a jet at 7 TeV
- $Z \to \mu\mu$
  - $2.0 < \eta < 4.5,\ p_T > 20\,\text{GeV},\ 60 < M_{\mu\mu} < 120\,\text{GeV}$
- jets
  - ParticleFlow and anti-k_T algorithm (**R=0.5**)
  - $p_T > 10/20\,\text{GeV},\ 2.0 < \eta(j) < 4.5$
- $\Delta R(Z, jet) > 0.4$
- purity of Z+jet determined as in inclusive analysis using data-driven methods



- Jet energy correction determined from simulation
  - $\sim$ 0.9 - 1.1
- Jet energy resolution $\sim 10 - 15\%$

Z+Jet at 7 TeV - Results





- Data compared to NLO predictions using POWHEG + Pythia (Parton Shower)
- In general predictions describe the data well

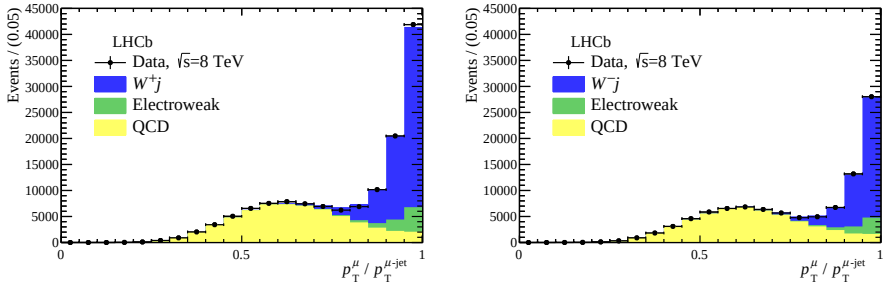
Z+Jet at 7 TeV - Systematic Uncertainties

Source	Relative uncertainty (%)
Unfolding	1.5
Z detection and reconstruction	3.5
Jet-energy scale, resolution and reconstruction	7.8
Final state radiation	0.2
Total excluding luminosity	8.6
Luminosity	3.5

- dominant uncertainty comes from jet energy scale
  - determined by comparing agreement in ratio of Z boson and jet in Z+1-jet events
- a number of correlated systematic uncertainties between bins, accounted for in total fiducial cross-section
- no covariance matrix published for analysis
- analysis available in Rivet as LHCB_2014_I1262703

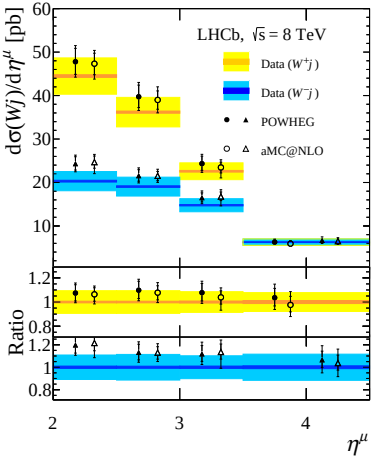
W/Z+Jet at 8 TeV

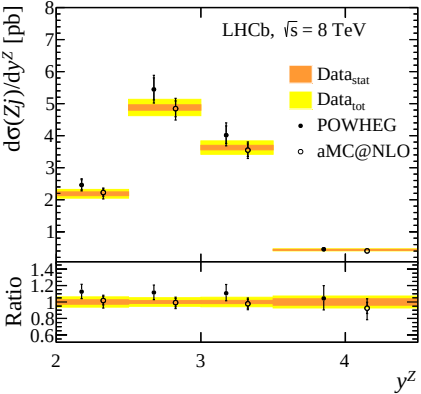
AbellanBeteta:2016ugk



- measurements made of both W and Z production in association with jets at 8 TeV
- same fiducial as Z+jet with tighter fiducial requirement on jet ($2.2 < \eta^j < 4.2$)
- same jet reconstruction algorithms used
- purity of Z+jet determined from data-driven methods ($\sim 99\%$)
- purity of W+jet determined with fit to isolation variable

W/Z+Jet at 8 TeV - results

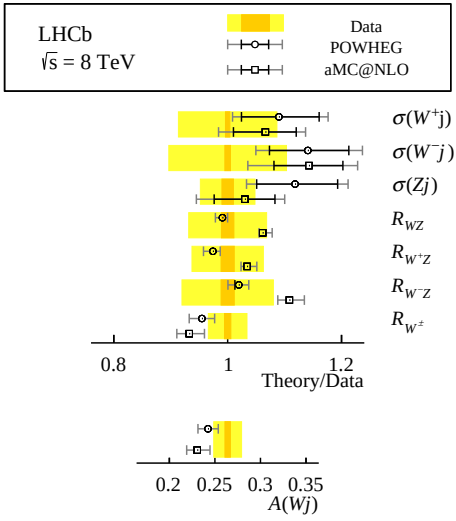




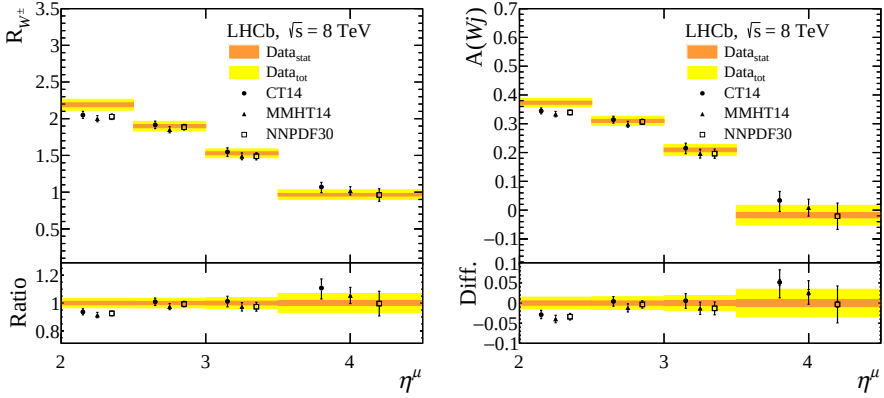
- a large number of differential distributions measured
  - η^{jet}, $p_{\text{T}}^{\text{jet}}$, $\eta^{\mu}(W)$, y^{Z}, $\Delta\phi$ (Z)

W/Z+Jet at 8 TeV - results

- all covariance matrices provided at `https://cds.cern.ch/record/2150413` as supplementary material
  - 12 in total
- a number of derived quantities are determined using covariance matrices
  - total cross-sections, W^+/W^- ratios, W/Z ratios
- predictions for cross-section measurements limited by scale uncertainties
- however ratios/asymmetries become sensitive to high-x PDFs



W/Z+Jet at 8 TeV - results (II)



- charge ratio and asymmetry sensitive to PDF effects

W/Z + jet - systematic uncertainties

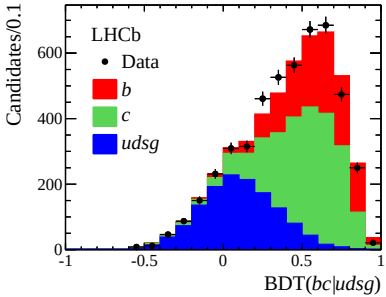
Source	σ_{W^+j}	σ_{W^-j}	$\sigma_{Z+\text{jet}}$	R_{WZ^0}	$R_{W^\pm}$
Statistical	0.4	0.5	1.1	1.2	0.7
Muon reconstruction	1.3	1.3	0.6	0.9	0.0
Jet reconstruction	1.9	1.9	1.9	0.0	0.0
Selection	1.0	1.0	0.0	1.0	0.0
GEC	0.5	0.5	0.4	0.2	0.1
Purity	5.5	7.0	0.4	6.0	2.5
Acceptance	0.6	0.6	0.0	0.6	0.0
Unfolding	0.8	0.8	0.8	0.0	0.2
Jet energy	6.5	7.7	4.3	3.4	1.2
Total Systematic	8.9	10.7	4.8	7.0	3.3
Luminosity	1.2	1.2	1.2	–	–

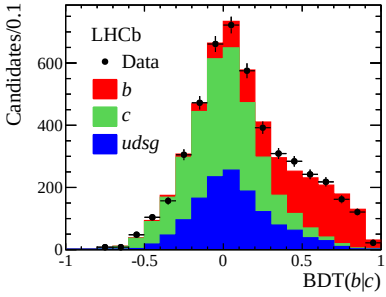
- largest uncertainty due to jet energy scale for Z+jet measurements
  - total uncertainty halved from 7 TeV measurement
- purity and jet energy contribute at similar level for W+jet
- covariance matrices not currently provided for individual contributions, but could be if needed

W + b,c at 7, 8 TeV

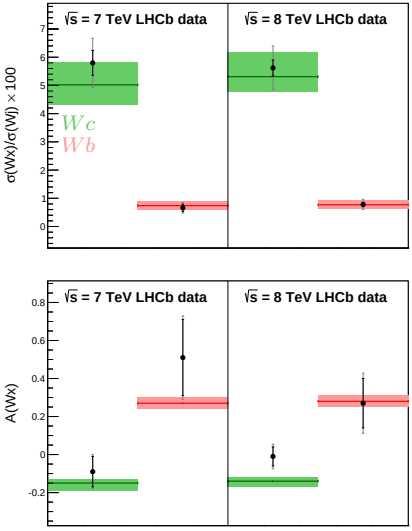
Aaij:2015cha

- $W + b, c$-jet cross-sections measured using same selection as W/Z+jet analysis at both 7 and 8 TeV
- jets tagged using secondary vertex tagger
- b and c jet yields simultaneously extracted using fit to BDT distributions designed to separate beauty and charm, and heavy flavour and light jets





$W + (b, c)$ results



- measurements of ratios with respect to Wj and charge asymmetries
- good level of data/theory agreement observed
- experimental measurements dominated by statistical uncertainties
- b- and c-tagging uncertainties determined from data ($\approx 10\%$)
- measured Wc asymmetries $\approx 2\sigma$ smaller than SM expectations

$W + (b, c)$ - **systematic uncertainties**

Source	$\frac{\sigma(Wb)}{\sigma(Wj)}$	$\frac{\sigma(Wc)}{\sigma(Wj)}$	$\frac{\sigma(Wj)}{\sigma(Zj)}$	$\mathcal{A}(Wb)$	$\mathcal{A}(Wc)$
Muon trigger and selection	–	–	2%	–	–
GEC	1%	1%	1%	–	–
Jet reconstruction	2%	2%	–	–	–
Jet p_T	2%	2%	1%	0.02	0.02
(b, c)-tag efficiency	10%	10%		–	–
SV-tag BDT templates	5%	5%		0.02	0.02
$p_T(\mu)/p_T(j_\mu)$ templates	10%	5%	4%	0.08	0.03
Top quark	13%	–	–	0.02	
$Z \to \tau\tau$	–	3%	–	–	–
Other electroweak	–	–	–	–	–
$W \to \tau \to \mu$	–	–	1%	–	–
Total	20%	13%	5%	0.09	0.04

- cross-sections measured relative to Wj cross-section
- largest uncertainties come from purity and tagging efficiency
  - large portion of tagging uncertainty is 100% **anti**-correlated between $W + b$ and $W + c$

conclusion

- LHCb has three main V+jet analyses published during Run 1
- only Z+jet at 7 TeV available on Rivet, will look to add the others
- full covariance matrices published for W/Z+jet at 8 TeV
  - if more detailed information is required (i.e. breakdown of covariance matrices), this can be provided

backup