Measurement of the production cross section for a c-quark jet in association with a W boson with the ATLAS detector at the LHC

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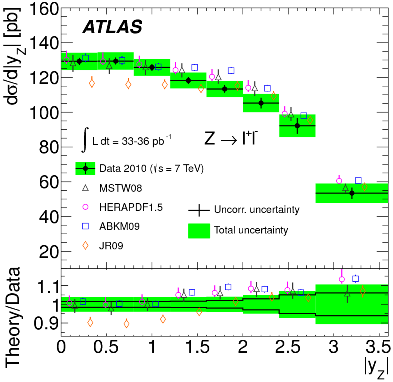
Motivation: *s*-quark Parton Density Function (PDF)



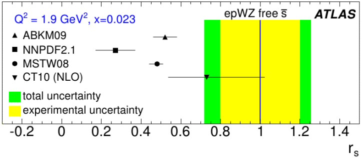
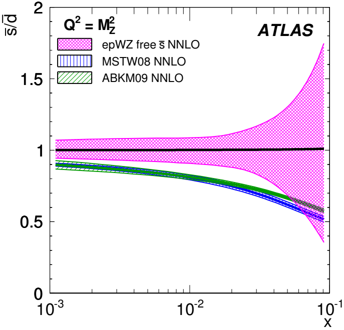


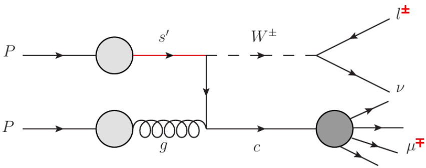
FIG. 2. Predictions for the ratio $r_s = 0.5(s + \bar{s})/\bar{d}$, at $Q^2 = 1.9\,\mathrm{GeV}^2$, $x = 0.023$. Points: global fit results using the PDF uncertainties as quoted; bands: this analysis; inner band, experimental uncertainty; outer band, total uncertainty.



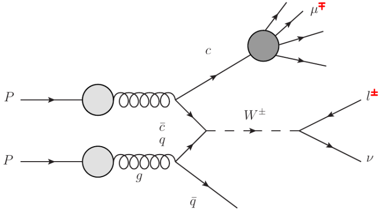
- *s*-quark PDF known with high uncertainty at low *x*
- ATLAS W and Z cross section results (arXiv:1203.4051) → *s*-quark proton content enhanced

The W+c cross section measurement

The aim is a cross section measurement for W+c final states, which may be used to constrain the s-quark pdf.



LO(sg)



NLO(gg)

- measurement in $W \to e\nu$ and $W \to \mu\nu$ channels
- cross section measured exclusively in 1-jet bin (80% *sg*) and 2-jets bin (50% *sg*, 20% *gg*)
- the strategy is to select final states using $c \to \mu + X$ decays
- the direct outcome is a $\sigma^{\mathrm{fid}}_{\mathrm{Wc}(c\to\mu)} \times \mathrm{BR}(W \to \ell\nu)$ cross section measurement
- this is extrapolated to a $\sigma^{\mathrm{fid}}_{\mathrm{Wc}} \times \mathrm{BR}(W \to \ell\nu)$ cross section relying on simulations

W boson selection

- Isolated e or μ: $p_{\mathrm{T}} > 25(20)$ GeV, $|\eta| < 2.5(2.4)$
- High missing transverse energy: $E_T^{miss} > 25(20)$ GeV
- High transverse mass: $m_T^W > 40(60)$ GeV

Black numbers are for the electron channel, blue numbers for the muon channel

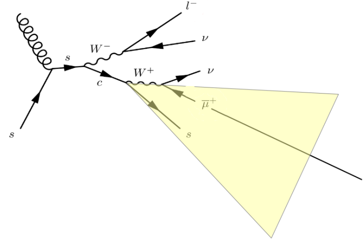
Jet selection

- 1 or 2 jets with $p_{\mathrm{T}} > 25$ GeV, $|\eta| < 2.5$
- exactly 1 jet with a soft muon inside

  i.e. tagged by the Soft Muon Tagger (see next slide)

$q^{Wlepton} q^{soft\ muon} > 0 \rightarrow$ SS bin; $q^{Wlepton} q^{soft\ muon} < 0 \rightarrow$ OS bin.
Signal is totally asymmetric $\rightarrow$ OS bin only.
Backgrounds are mostly symmetric $\rightarrow$ doing OS-SS results in background subtraction.

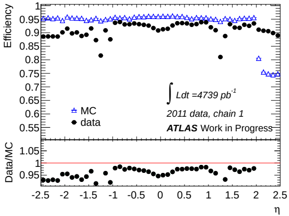
The Soft Muon Tagger (SMT)



- *b*-jets and *c*-jets selected using soft muons from hadron decays
- low BR (10%) but high rejection power vs light-jets
- Light-jets rejection is R≈470, mistag rate is $O(10^{-3})$
- In *Wc* events especially useful due to charge anticorrelation

SMT calibration

- muon reconstruction scale factors evaluated in data:
  - $J/\Psi \to \mu\mu$ at low p_{T}
  - $Z \to \mu\mu$ at high p_{T}
- mistag rate calibrated in data in multijet events



Efficiency measurement in data and simulations in $Z \to \mu\mu$ events

- $t\bar{t}$, single-top, diboson are small: estimated on MC
- $W + c\bar{c}$ and $W + b\bar{b}$ are symmetric, OS-SS=0, can be neglected
- $W + b$ is Cabibbo supressed
- $Z + jets$:
  - small in electron channel, taken from MC
  - relevant in muon channel (because of SMT, with one of the Z muons falling inside one jet), estimated in data
- For W+light-jets and QCD multi-jet, the relevant quantities are the normalization and the OS/SS asymmetry α: these are evaluated on data (techniques similar to the ones described in arXiv:1109.1470)

Estimated background in the muon channel after OS-SS subtraction

Estimated background is at 15% level in the 1 jet bin, 25% in the 2 jets bin

The extrapolation factors are evaluated on a Wc Alpgen+Pythia MC sample:

$Wc(c \to \mu)$ cross section

$$\sigma^{\text{fid}}_{\text{Wc}(c\to\mu)} \times \text{BR}(W \to \ell\nu) = \frac{N^{OS-SS}_{data} - N^{OS-SS}_{bkg}}{U \cdot \int \mathcal{L}dt}$$

$$U = \frac{N^{Wc,OS-SS}_{MC,reco}(\text{analysis cuts})}{N^{Wc,OS-SS}_{MC,truth}(\text{fiducial cuts})}$$

- U is the efficiency of the analysis selection on signal in the fiducial phase space

Wc cross section

$$\sigma^{\text{fid}}_{\text{Wc}} \times \text{BR}(W \to \ell\nu) = \frac{N^{OS-SS}_{data} - N^{OS-SS}_{bkg}}{B \cdot U \cdot \int \mathcal{L}dt}$$

$$B = \frac{N^{Wc,OS-SS}_{MC,truth}(\text{fiducial cuts})}{N^{Wc,OS-SS}_{MC,truth}(\text{fiducial cuts without soft muon requirements})}.$$

- B is the unfolding factor from $Wc(c \to \mu)$ to Wc in the fiducial phase space

Branching Ratio

- BR of different c-hadrons to muon is reweighted separately for each species to PDG values
- the PDG error is used as systematic

p^* (muon momentum in c-hadron rest frame)

- p^* of the soft muon is reweighted separately for each c-hadron species to EvtGen shape
- The systematic is evaluated as the difference with Pythia

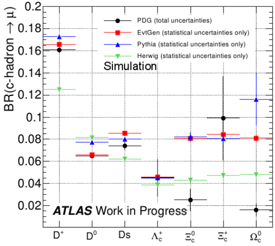
Fragmentation function (p_T^{hadron}/p_T^{jet})

- (large) difference between Herwig and Pythia is used as a systematic uncertainty

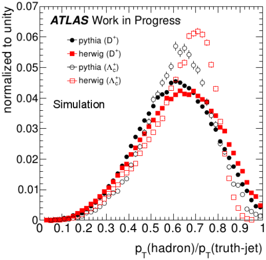
Fragmentation fraction (fraction of c-hadron species)

- Central value from HERA paper (arXiv:1112.3757v1, arXiv:1211.1182) used to reweight
- Errors used as systematic uncertainties

BR to muons of different c-hadrons



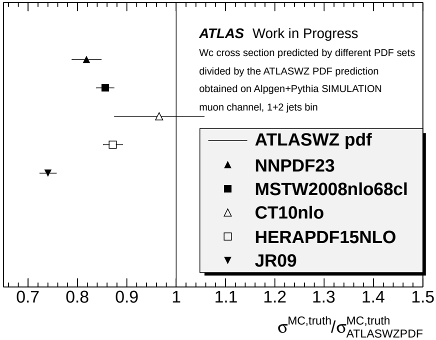
Fragmentation function in Herwig and Pythia



Systematic uncertainties in the muon channel

- Combining 1 and 2 jets bin, data statistics uncertainty is at 2.5% level
- Uncertainties due to background normalizations are dominated by W+light-jets uncertainty, ≈1.5%
- Detector uncertainties are dominated by muon reconstruction and Jet Energy Scale uncertainties, both at ≈3% level
- c-hadron fragmentation and decay uncertainties are relevant, at ≈3% level
- Unfolding uncertainty due to PDF description is small, ≈1%

Predicted cross section with different PDF sets



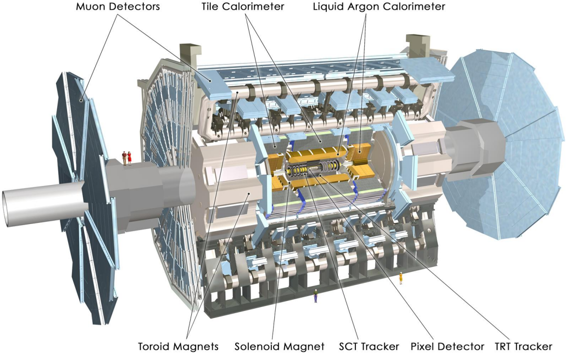
- The plot shows the Alpgen+Pythia predictions for the Wc cross sections with different PDF sets
- Uncertainty on the ATLASWZ prediction is not shown, it is expected to be at the same level as the CT10nlo one.
- The ratio wrt the central value of the predictions obtained with the ATLAS W/Z results (arXiv:1203.4051) is shown
- The Wc measurement is clearly sensitive to the s-quark PDF
- The final results for the measurement are in preparation

Conclusions

- The analysis is close to final
- The background estimation is complete
- The cross section extraction and the systematic uncertainty evaluation are $\approx$completed
- We're currently working on a ratio $W^+\overline{c}/W^-c$ measurement and on a measurement differential in the $|\eta|$ of the W-lepton
- Main open points are the evaluation of a parton level cross section and the usage of the results for s-quark PDF constraints

BACKUP

The ATLAS detector



Subdetectors

- Inner Detector (solenoidal field)
  - Silicon tracker up to $|\eta| < 2.5$
- Calorimeters
  - EM up to $|\eta| < 3.2$
    - Liquid Argon sampling calorimeter
  - Hadronic up to $|\eta| < 4.9$
    - Tile sampling calorimeter
    - Liquid Argon Calorimeter (forward)
- Muon Spectrometer (toroidal field)
  - Tracking up to $|\eta| < 2.7$
  - Trigger up to $|\eta| < 2.4$

Physics process	Datasets ID	Generators	$\sigma \cdot$BR (nb)
$W \rightarrow l\nu + c$	126601-126605	ALPGEN [22]+PYTHIA [23]	
$W \rightarrow l\nu$ +jets	107680-107705	ALPGEN [22]+HERWIG [24]	
$W \rightarrow l\nu + b\bar{b}$	107280-107283	ALPGEN [22]+HERWIG [24]	
$W \rightarrow l\nu + c\bar{c}$	107284-107287	ALPGEN [22]+HERWIG [24]	
Total $W \rightarrow l\nu$ + jets			10.46 NNLO [25]
$Z \rightarrow ll$ +jets	107650-107675	ALPGEN [22]+HERWIG [24]	1.07 NNLO [25, 26]
WW	105985	HERWIG [24]	44.9×10^{-3} NLO [27]
WZ	105986	HERWIG [24]	18.5×10^{-3} NLO [27]
ZZ	105987	HERWIG [24]	5.96×10^{-3} NLO [27]
$t\bar{t}$	105200	MC@NLO [28]+HERWIG [24]	90.5×10^{-3} approx.NNLO [29]
singletop (t-channel)	117360-117362	ACERMC [30]+PYTHIA [23]	64.6×10^{-3} NNLO [31]
singletop (s-channel)	108343-108345	MC@NLO [28]+HERWIG [24]	4.6×10^{-3} NNLO [32]
singletop (Wt)	108346	MC@NLO [28]+HERWIG [24]	15.7×10^{-3} NNLO [33]

Table 1: Simulated samples used for the analysis.