

V+heavy flavor jets and constraints to PDFs

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- Provides precise test of QCD and EWK sectors
 - ME-calculation and matching to parton shower

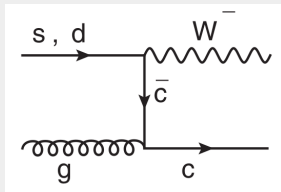
- Sensitivity to parton distribution functions
 - validation of pdfs at lower energies
 - constraints for more precise pdfs extraction

- Irreducible background for other precise measurements and searches for new physics

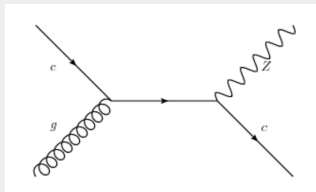


Measurements presented in this Talk

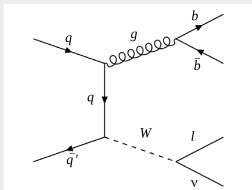
W+c (7 TeV)



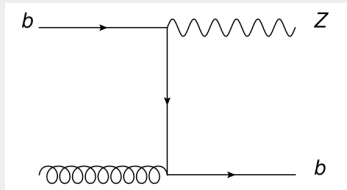
Z+c (8 TeV)

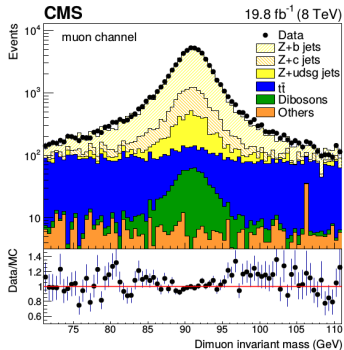


W+bb (8 TeV)



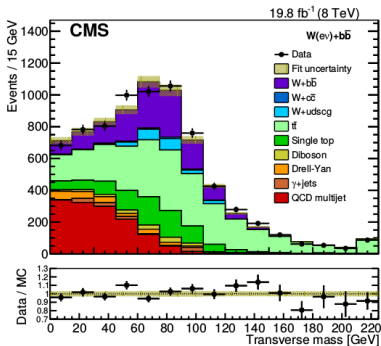
Z+b(b) (8 TeV)





$Z \rightarrow ll$

- $p_T^l > 20 \text{ GeV}$ ($l = e, \mu$)
- $71 < M_{ll} < 111 \text{ GeV}$
- $Z + c: |\eta^l| < 2.1$
- $Z + b: |\eta^l| < 2.4$



$W \rightarrow l\nu$

- $W + c: p_T^e > 35 \text{ GeV}$ $p_T^\mu > 25 \text{ GeV}$
- $W + b\bar{b}: p_T^l > 30 \text{ GeV}$ ($l = e, \mu$)
- $|\eta^l| < 2.1$
- $W + c: M_T^e > 55 \text{ GeV}$ $M_T^\mu > 40 \text{ GeV}$

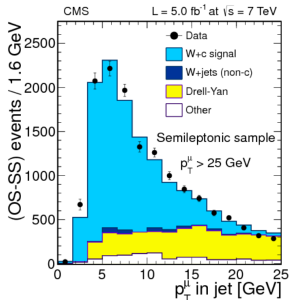


c-jet Reconstruction

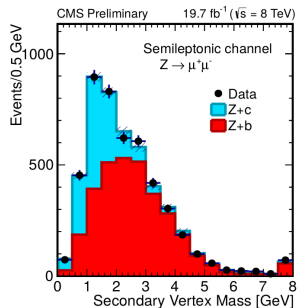
$W + c, Z + c$

Semileptonic Channel

- Muon inside a jet
- $p_T(\mu) < 25 \text{ GeV}$
- $p_T(\mu)/p_T(\text{jet}) < 0.6$



[JHEP 02 (2014) 013]



[CMS-PAS-SMP-15-009]

- Jet Selection: $p_T^{\text{jet}} > 25 \text{ GeV}$, $|\eta^{\text{jet}}| < 2.5$
- $W + c$: $(W^+ + \mu^-) - (W^+ + \mu^+)$ (OS-SS)
- $Z + c$: Template fit to secondary-vertex mass

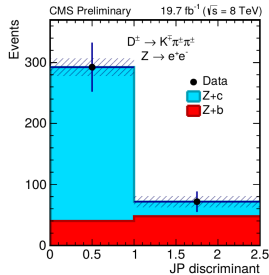
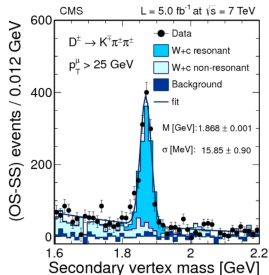


c-jet Reconstruction

$W + c, Z + c$

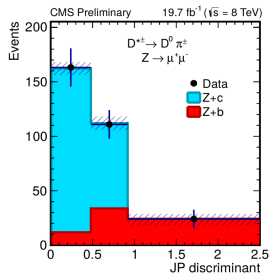
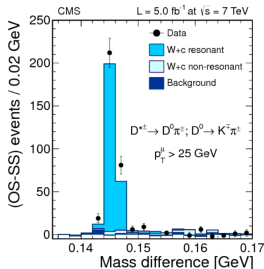
$$D^\pm \rightarrow K^\mp \pi^\pm, \pi^\pm$$

- 3 track secondary vertex
- m_{inv} consistent with D^\pm
- Template fit to Jet Probability discriminant (JP) ($Z + c$)



$$D^{*\pm} \rightarrow D^0 \pi_s^\pm, D^0 \rightarrow K^\mp \pi^\pm$$

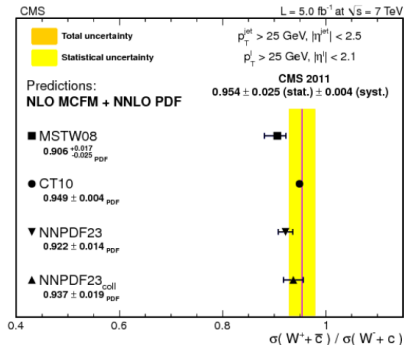
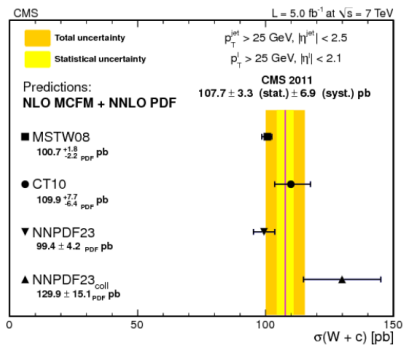
- 2 track secondary vertex (D^0) + extra track (π_s^\pm)
- $\Delta M(D^*, D^0) - 0.145 \text{ GeV} < 5 \text{ MeV}$





Inclusive Cross-Section

$W + c$

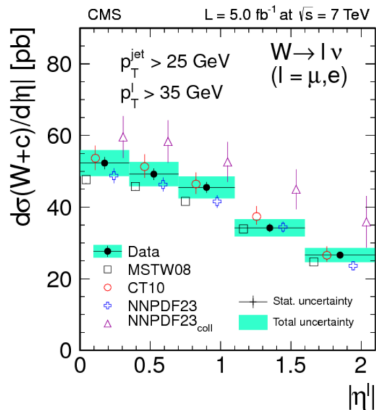


- Direct probe of strange-quark content of the proton
- Access to $s\bar{s}$ -asymmetry

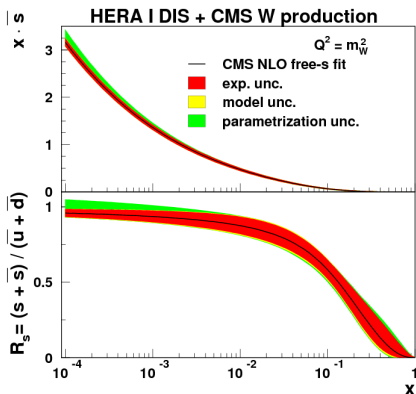


Differential Cross-Section

$W + c$



[JHEP 02 (2014) 013]



[Phys.Rev. D90 (2014) no.3]

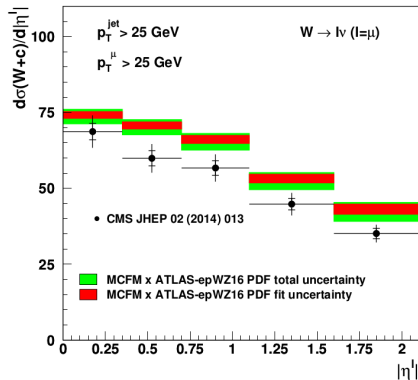
- Good agreement for pdfs with lower energy charm data
- Has been used to perform pdf-extractions



NNLO ATLAS-epWZ16

[arXiv:1612.03016]

- s-quark PDFs determined by analysis of W and Z/γ^* measurements
 - 7 TeV + HERA-DIS data
 - inclusive + differential
- ATLAS analysis suggests large strangeness in the proton



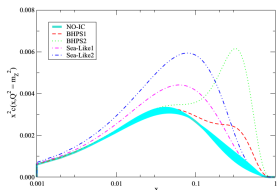
[Plot by K. Lipka]



Inclusive Cross-Section

$Z + c$

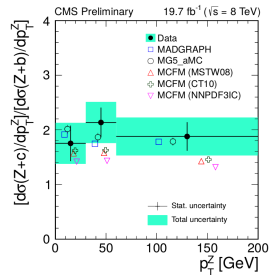
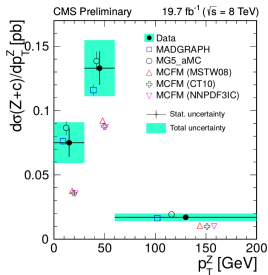
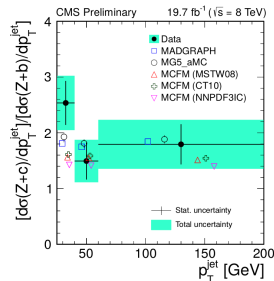
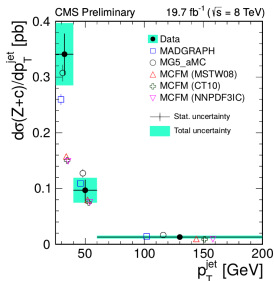
- Important background for Searches (FCNC)
- Probe of charm content at EW-scale
- Search for intrinsic charm



[arXiv:1512.06007]

	$\sigma(pp \rightarrow Z + c + X)$	$\frac{\sigma(pp \rightarrow Z + c + X)}{\sigma(pp \rightarrow Z + b + X)}$
Measured [pb]	$8.6 \pm 0.5(\text{stat.})$ $\pm 0.7(\text{syst.})$	$2.0 \pm 0.2(\text{stat.})$ $\pm 0.2(\text{syst.})$
Madgraph5 (LO) [pb]	$8.14 \pm 0.03(\text{stat.})$ $\pm 0.25(\text{PDF})$	$1.805 \pm 0.006(\text{stat.})$ $\pm 0.004(\text{PDF})$
MG5-aMC@NLO [pb]	$9.47 \pm 0.04(\text{stat.})$ $\pm 0.15(\text{PDF})$ $\pm 0.5(\text{scale})$	$1.87 \pm 0.07(\text{stat.})$ $\pm 0.5(\text{scale})$

- Both MadGraph samples show good agreement with data
- MCFM predictions are lower than data
- No difference when using PDFs with and without intrinsic charm



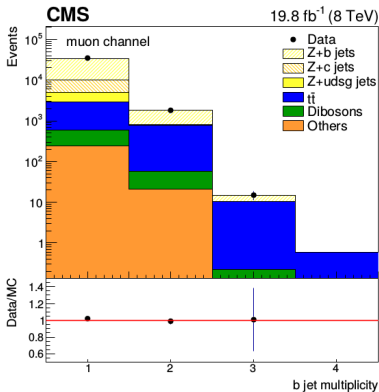


b-jet Reconstruction

$W + b\bar{b}$, $Z + b(b)$

- $W + b\bar{b} : p_T^{jet} > 25 \text{ GeV}$
- $Z + b(b\bar{b}) : p_T^{jet} > 30 \text{ GeV}$

- $|\eta^{jet}| < 2.4$
 - $W + b\bar{b}$: no extra jets in $|\eta| < 4.7$
- Cone-Size (ΔR) = 0.5
- Combined Secondary Vertex (CSV) b-tagging



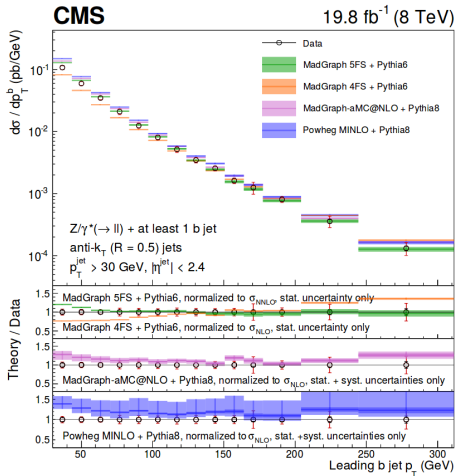
[arXiv: 1611.06507]



Differential Cross-Section

$Z + b(b)$

- Large background for $Z + H$ ($H \rightarrow b\bar{b}$) and searches
- Test of heavy flavor sector
- fixed 4 flavor scheme
 - $g \rightarrow b\bar{b}$ absent from pdf
 - massive b -quark in Matrix-Element
- variable 5 flavor scheme
 - $g \rightarrow b\bar{b}$ can contribute to pdf
 - massless b quark in Matrix-Element

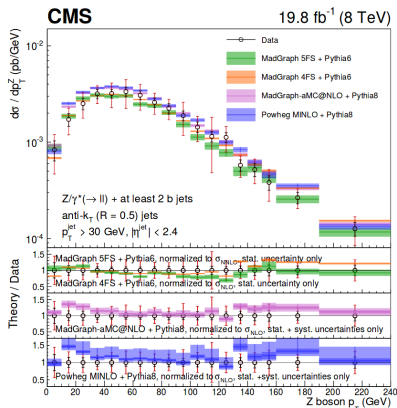
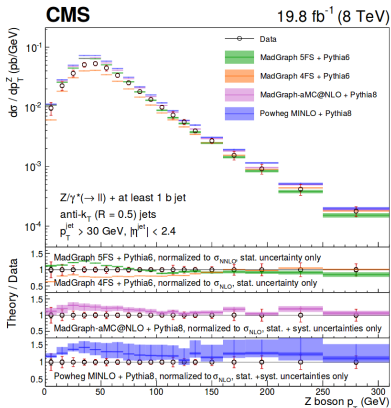


[arXiv: 1611.06507]



Differential Cross-Section

$Z + b(b)$



[arXiv:1611.06507]

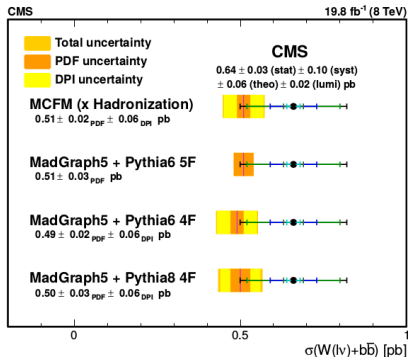
- All predictions show similar degree of agreement with data
- $Z + b$: None describe low- p_T region well
- $Z + b\bar{b}$: Large systematic uncertainties



Inclusive Cross-Section

$W + b\bar{b}$

- Test of pQCD calculations
- Important background for Higgs, $t\bar{t}$ and searches
- Comparison to different predictions:
 - NLO MCFM (MSTW2008)
 - LO MADGRAPH5
 - + Pythia6 4FS (NNPDF2.3 LO)
 - + Pythia6 5FS (CTEQ6L)
 - + Pythia8 4FS (NNPDF2.3 LO)



[EPJC 77 (2017) 92]

$$\sigma(\text{pp} \rightarrow \text{W} + \text{b}\bar{\text{b}}) = 0.64 \pm 0.03 \text{ (stat)} \pm 0.10 \text{ (syst)} \\ \pm 0.06 \text{ (theo)} \pm 0.02 \text{ (lumi)} \text{ pb}$$



Conclusion

V + heavy flavour jets

- Test of the QCD and EWK sectors
- Important background to Higgs + searches
- Provide constraints for pdf extractions
- V + heavy flavor analyses for $\sqrt{s} = 13$ TeV are ongoing