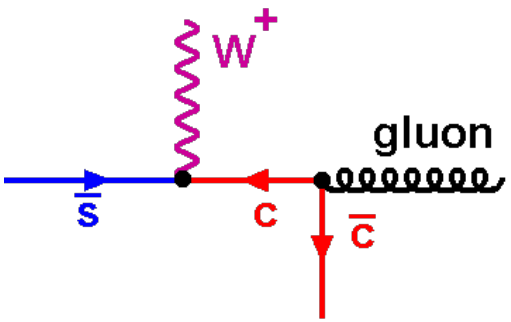
Vector Boson production with heavy flavor quarks from CMS



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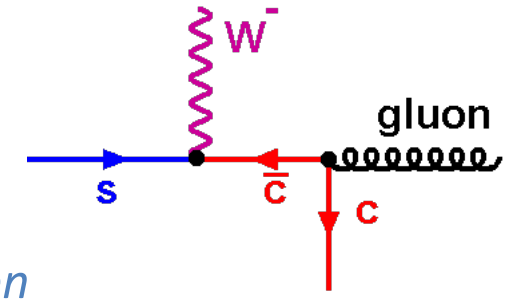
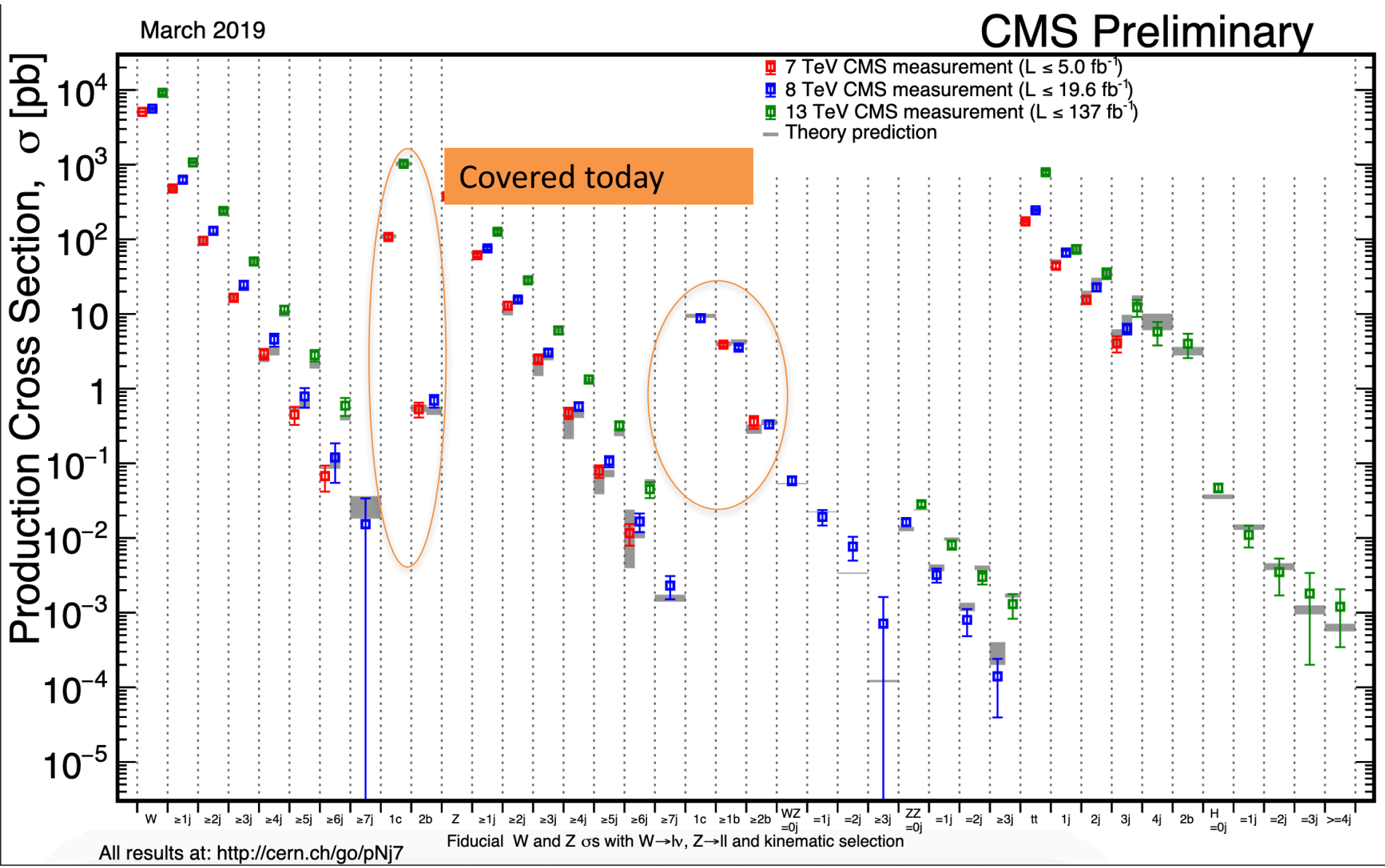
on behalf of CMS Collaboration

LHCP 2019
Puebla MEXICO



Status by March 2019



MOTIVATION

→Processes involving W & Z boson production are one of the better understood processes at hadron colliders

→W->lν , Z->ll, (l=e,μ) are among the cleanest final states experimentally

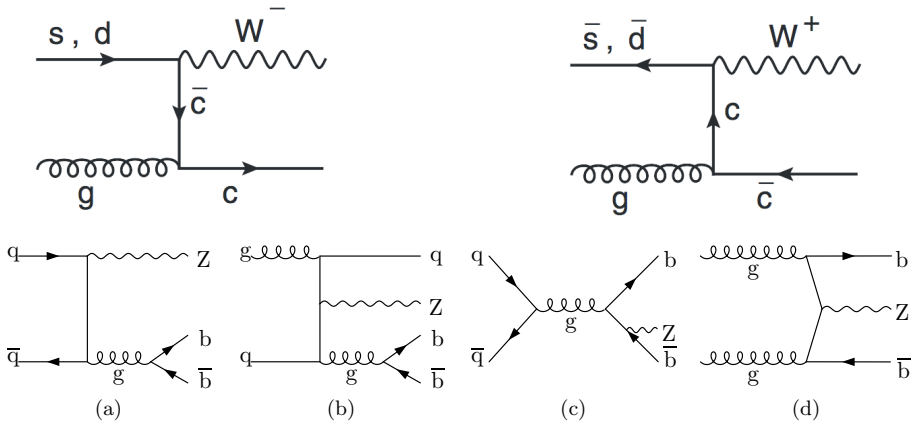
→ Important to study V+ HF production at the LHC

→ To test pQCD and validate MC

→ Probe HF PDFs

→ Collinear production of b quarks (gluon splitting)

→ They are backgrounds to other measurements and BSM searches



Example Feynman diagrams for W+c and Z + bb productions

→Measurements carried out in fiducial phase space

→corrected for detector effects

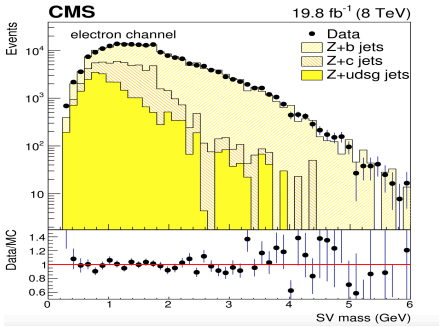
CONTENT

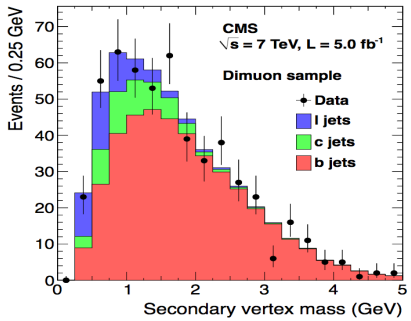
→Z+ b, bb jet cross sections at 7 TeV (JHEP 06 (2012) 126, JHEP 06 (2014) 120)
→Z+bb jets, b hadron angular correlations at 7 TeV (JHEP 12 (2013) 039)
→W+bb cross section at 7 TeV (PLB 735 (2014) 204)
→Measurement of Z + b jet at 8 TeV (Eur. Phys. J. C (2017) 77: 751)
→Measurement of W + bb jet at 8 TeV (Eur. Phys. J. C (2017) 77: 92)
→W+c differential cross section at 7 TeV (JHEP 02 (2014) 013)
→Measurement of Z + c jet at 8 TeV (Eur. Phys. J. C (2018) 78: 287)
→W+c differential cross section at 13 TeV (EPJC 79 (2019) 269)

V(Z,W) +>=1 b

p-p √s=7,8 TeV
5, 19.8 fb^{-1}

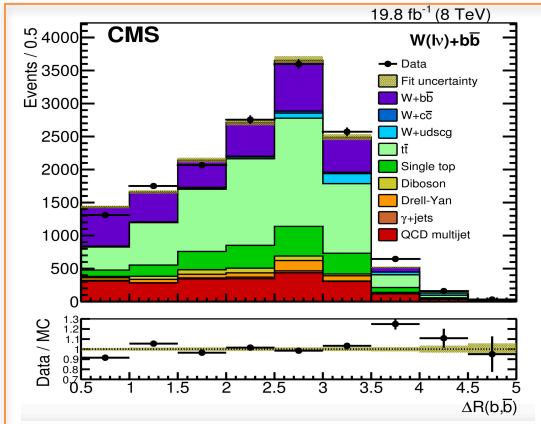
Z + >=1b		W + bb	
p_T^l >20 GeV, $\|\eta^l\|$<2.4			
76 <M_{ll}<106 GeV	71 <M_{ll}<111 GeV	p_T^l >25 GeV, $\|\eta^l\|$<2.1	p_T^l >30 GeV, $\|\eta^l\|$<2.1
p_T^j >25 GeV, $\|\eta^j\|$<2.1	p_T^j >30 GeV, $\|\eta^j\|$<2.4	two b-jets p_T^j >25 GeV, $\|\eta^j\|$<2.4	&& no other jets with p_T^j >25 GeV, $\|\eta^j\|$<4.7

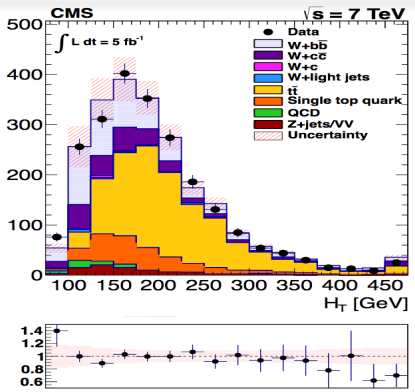


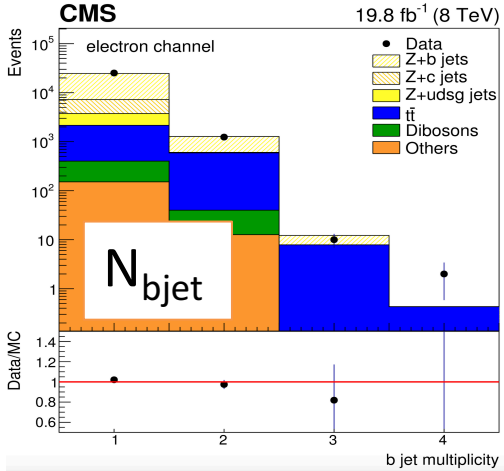


→SSV (CSV) algorithms to tag jets originating from b.
→ Chosen WP gives ~50% b- efficiency and ~1% of mistag rate

SV mass, input for b-tag algorithms







Z +b @8 TeV

p-p √s=7,8 TeV
5, 19.8 fb^{-1}

Studies of various variables are carried out

Z+b: p_T^b , η^b, p_T^Z, H_T, $\Delta\phi(Z,b)$

Z+bb: p_T^{b1} ,p_T^{b2}, p_T^Z,M^{bb} ,M^{Zbb} ,p_T^{bb}, $\Delta\phi(bb)$, $\Delta\phi(bb,Z)$, $\Delta R(bb)$…

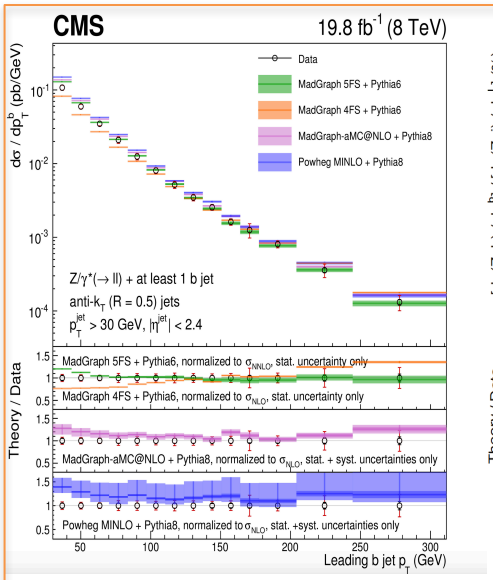
→ Sensitive to b-quark PDF and initial-state gluon splitting

→ Differences between PDF Flavor Schemes.

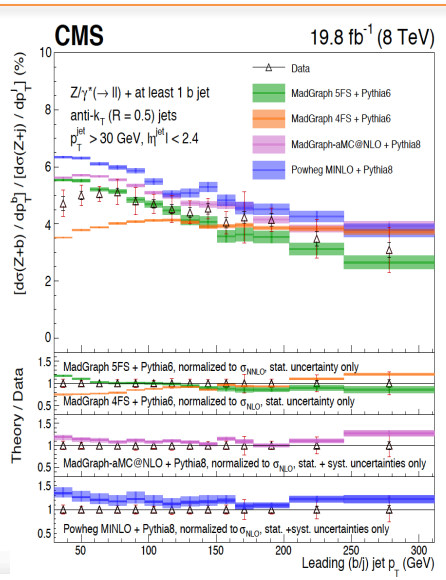
→ Sensitive to presence of heavy intermediate particles

$$A_{Zbb} = \frac{\Delta R_{Zb}^{max} - \Delta R_{Zb}^{min}}{\Delta R_{Zb}^{max} + \Delta R_{Zb}^{min}}.$$

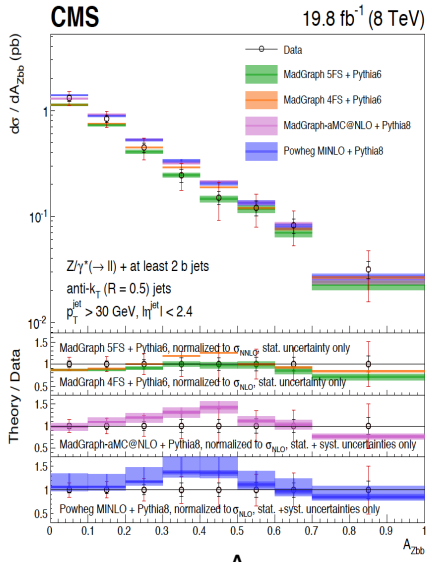
$$R(x) = \frac{d\sigma(Z+(\geq 1b))/dx}{d\sigma(Z+jets)/dx},$$



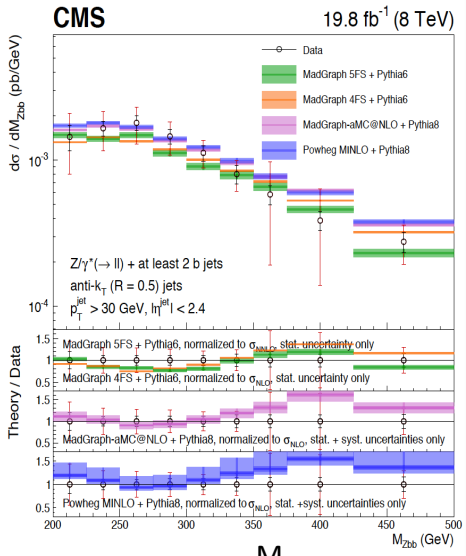
b-tagged jet p_T



b-tagged jet p_T/ light jet p_T



A_{ZBB}



M_{ZBB}

V(W,Z) +>=1 b

p-p √s=7,8 TeV
5, 19.8 fb^{-1}

Z+b results at 7 TeV

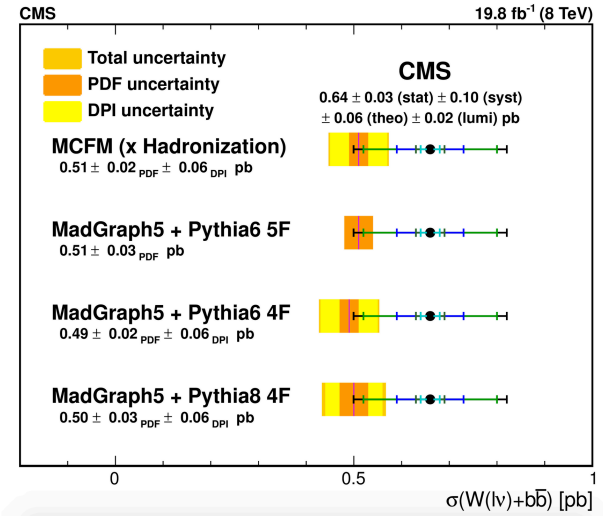
Cross section	Measured
σ_{Z+1b} (pb)	$3.52 \pm 0.02 \pm 0.20$
σ_{Z+2b} (pb)	$0.36 \pm 0.01 \pm 0.07$
σ_{Z+b} (pb)	$3.88 \pm 0.02 \pm 0.22$
$\sigma_{Z+b/Z+j}$ (%)	$5.15 \pm 0.03 \pm 0.25$

Z+b results at 8 TeV

Cross section	Measured
σ_{Z+1b} (pb)	3.55 +-0.12 +-0.2
σ_{Z+2b} (pb)	0.331+-0.011+0.035
σ_{Z+b} (pb)	---
$\sigma_{Z+b/Z+j}$ (%)	9.3 +- 0.4 +- 0.7

W(->lv) + 2b cross section at 7 TeV
0.53 +- 0.05 (stat) +-0.09 (syst)+-0.06 (theo.) +- 0.01 (lumi) pb

W(->lv) + 2b cross section at 8 TeV
0.64 +- 0.03 (stat) +-0.10 (syst)+-0.06 (theo.) +- 0.02 (lumi) pb



→ All measurements consistent with SM predictions and among each other

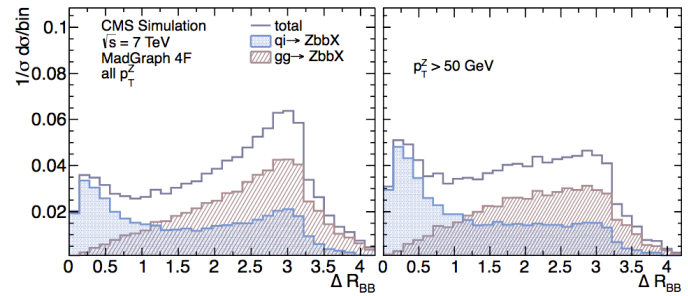
Z+ b hadrons

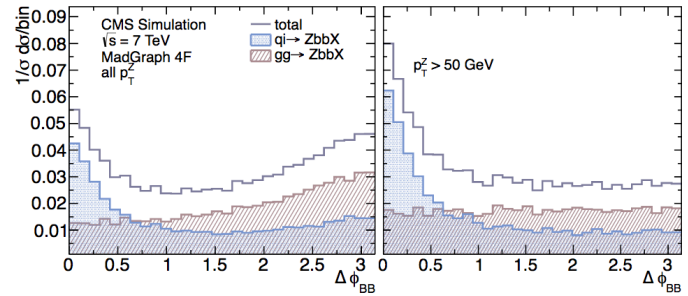
p-p √s=7 TeV
5 fb^{-1}

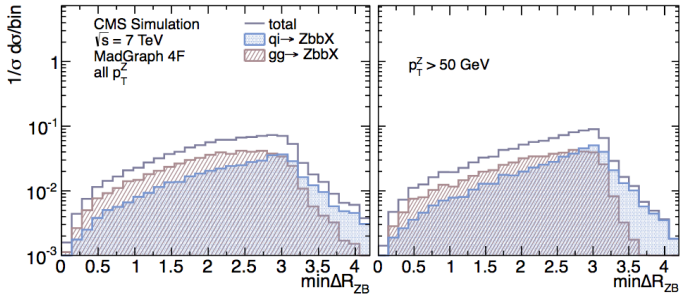
p_T^{l} >20 GeV, $|\eta^{l}|$<2.4 81 < M_{ll} < 101 GeV

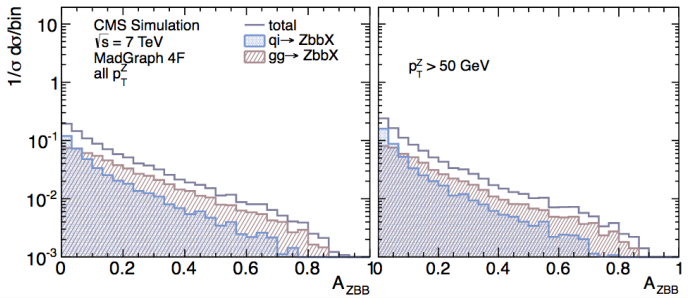
p_T^{b} >15 GeV, $|\eta^{b}|$<2

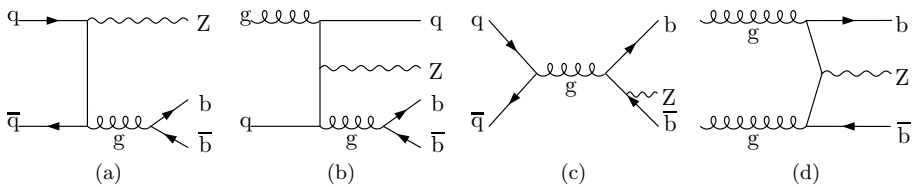
→ Study production of b hadrons associated with Z
- → B hadrons identified using displaced secondary vertices
- → No jet reconstruction, measurement not restricted to jet cone
  - → Can probe small ΔR region sensitive to g splitting







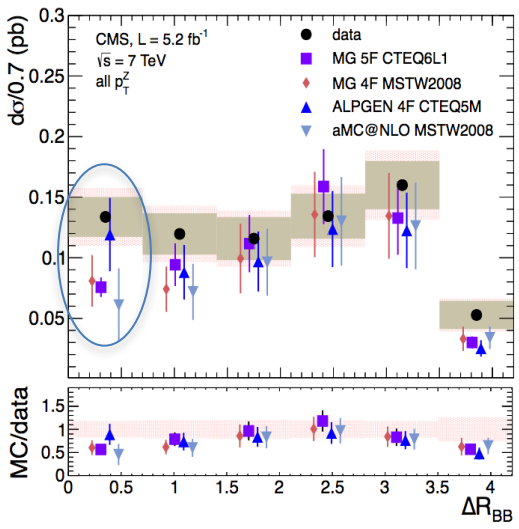


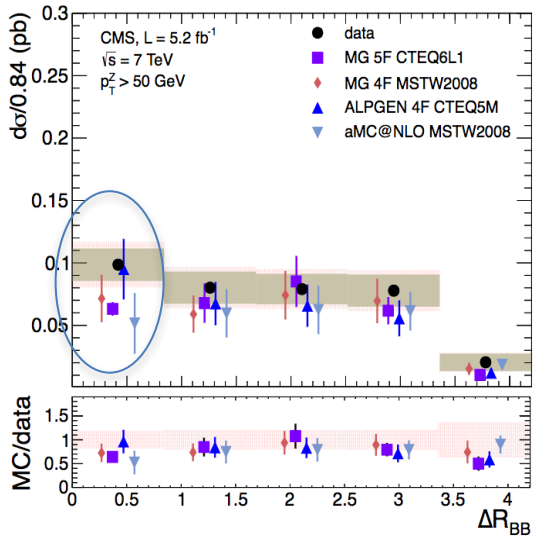


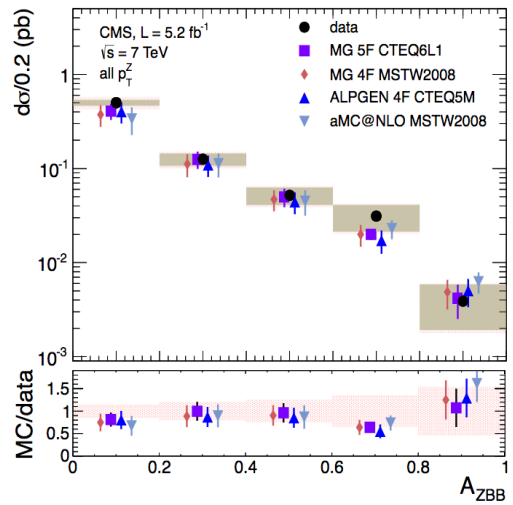
$$A_{\mathrm{Zbb}} = \frac{\Delta R_{\mathrm{Zb}}^{\mathrm{max}} - \Delta R_{\mathrm{Zb}}^{\mathrm{min}}}{\Delta R_{\mathrm{Zb}}^{\mathrm{max}} + \Delta R_{\mathrm{Zb}}^{\mathrm{min}}}.$$

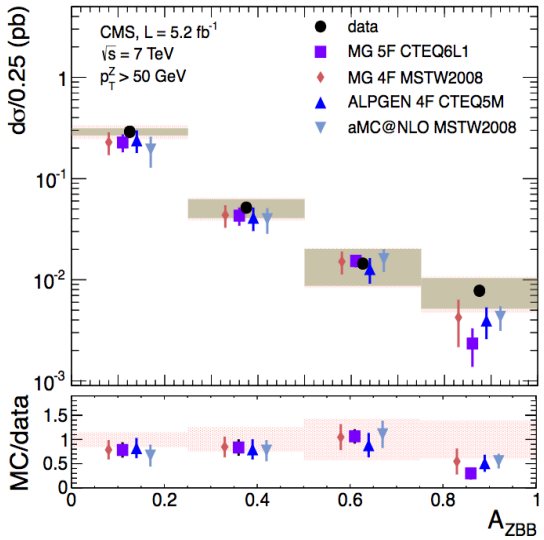
Z+ b hadrons

p-p √s=7 TeV
5 fb^{-1}









→ Study production of b hadrons associated with Z
  → No unfolding
  → Corrected for efficiency and acceptance
    → Bin to bin migrations are are accounted for as a source of systematic uncertainty

NEW

V(W,Z) + c

p-p √s=7,8,13 TeV
5, 19.8,35.7 fb^{-1}

p_T^l >21 GeV, $|\eta^l|$<2.1, 71<Mll<111 GeV

p_T^l >25 GeV, $|\eta^l|$<2.1

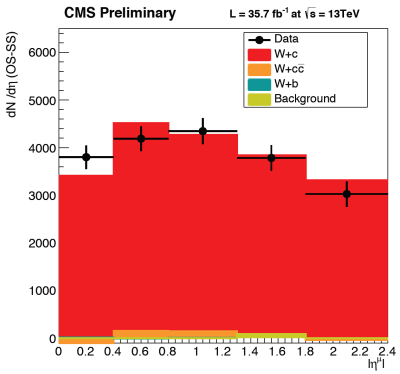
p_T^j >25 GeV, $|\eta^j|$<2.4

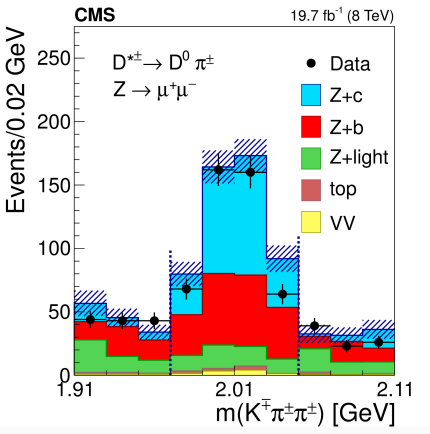
p_T^μ >26 GeV, $|\eta^\mu|$<2.4

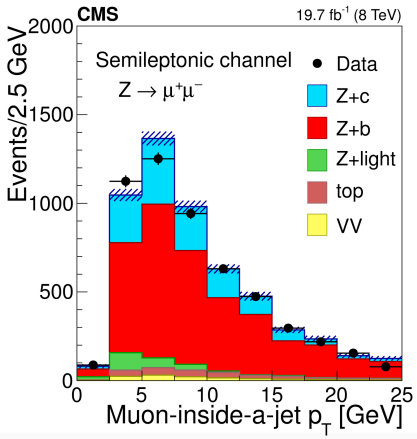
- → V + c measurements provide constraints to strange and charm PDF's
- → They provide BG's for searches

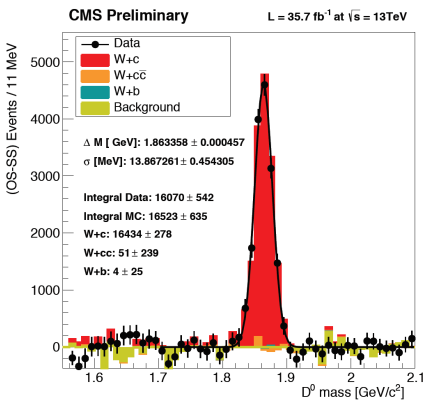
- → Tagging of heavy flavor jets carried out in 3 signatures (only 3rd for 13 TeV results)
  - → Semileptonic decay of hadron leading to a muon from a displaced vertex
  - → A displaced SV with 3 tracks consistent with D± decay
  - → A displaced secondary vertex with two tracks consistent with D^0 decay and associated to a previous $D^{*+}(2010)$ decay

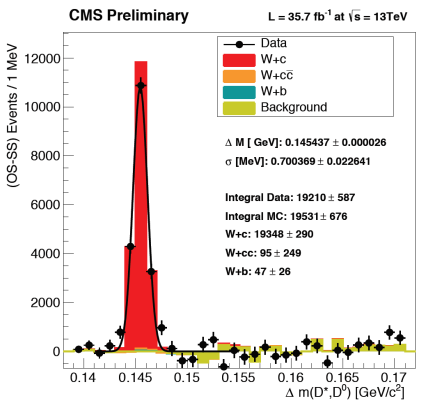
- → W+c: OS- SS method to substract BG
  - → BG contributions from the gluon splitting.









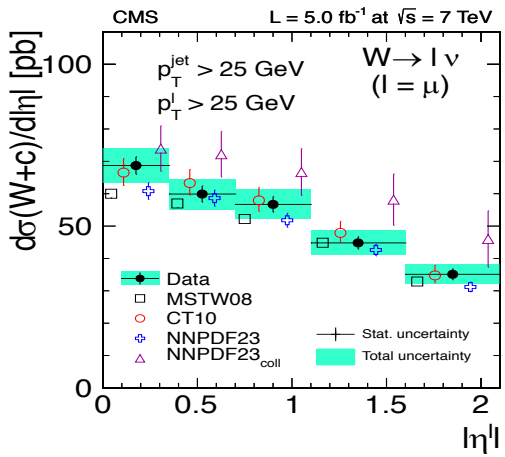


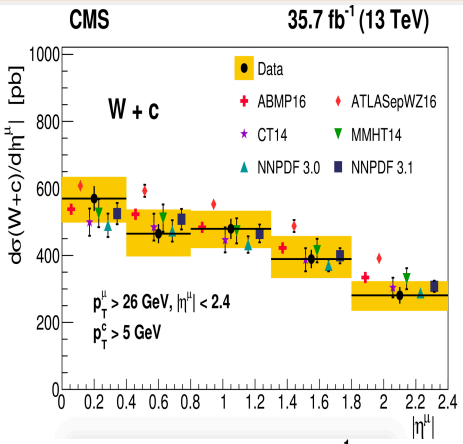
NEW

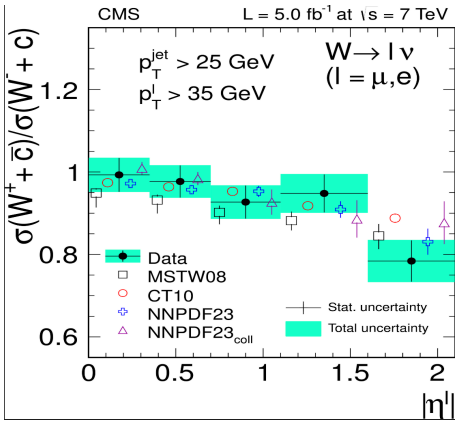
W + c

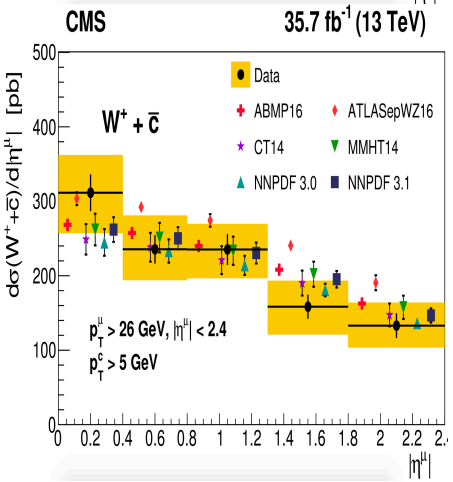
p-p √s=7,13 TeV
5,35.7 fb^{-1}

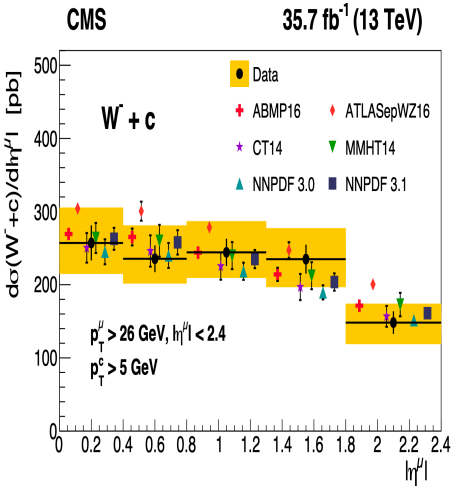
→ Measured W + c cross section as well as W$^+$+c/W$^-$+c ratio
  → inclusively
  → differentially wrt lepton η





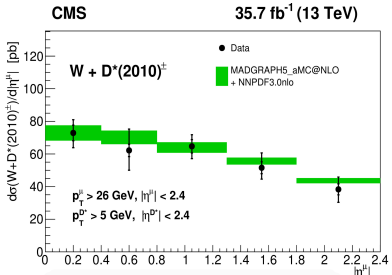


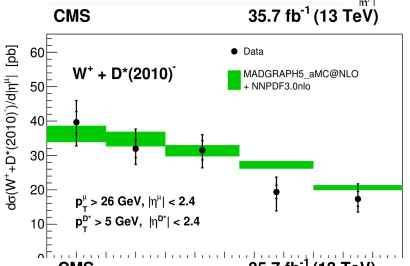


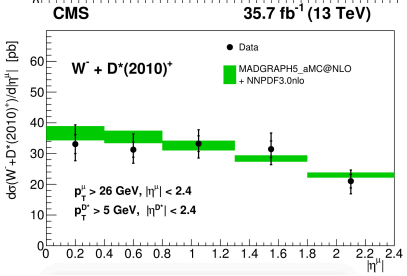


→ Differential W+ c and W$^+$+c/W$^-$+c cross section results

→13TeV: extrapolation to the unmeasured phase space
  → As cross check: W + D* x-sec is measured in fiducial range





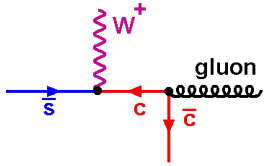


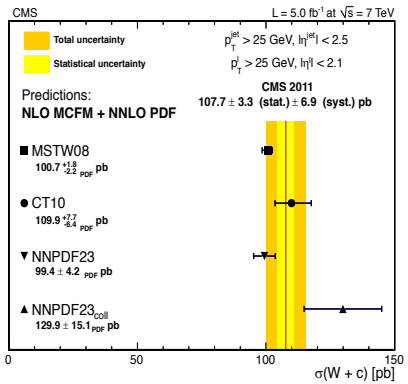
NEW

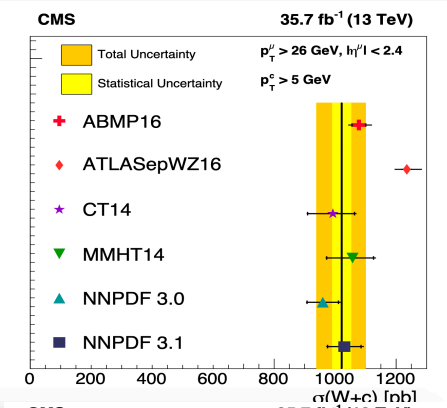
W + c

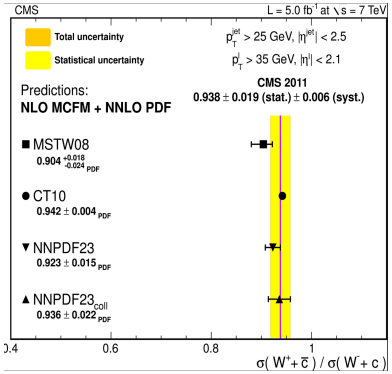
p-p √s=7,13 TeV
5,35.7 fb^{-1}

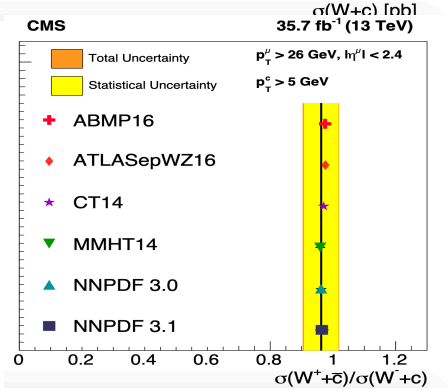
→ Measured W + c cross section as well as W^++c/W^-+c ratio
  → inclusively
  → differentially wrt lepton η





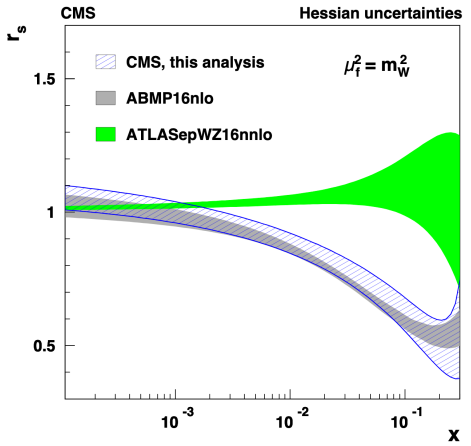






→ Comparison of W+c result to several sets of PDFs

→ Measurements used in a QCD analysis at NLO
Studying strange quark distribution and the strangeness suppression factor

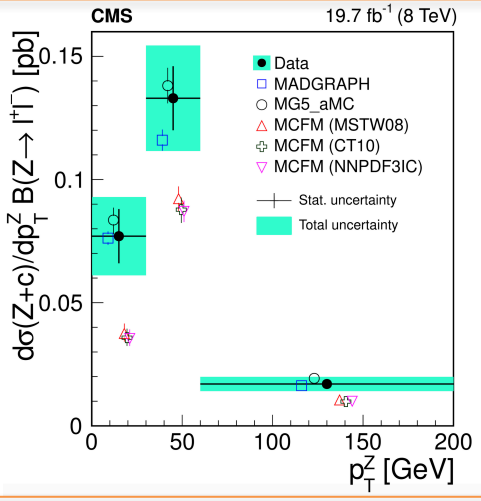


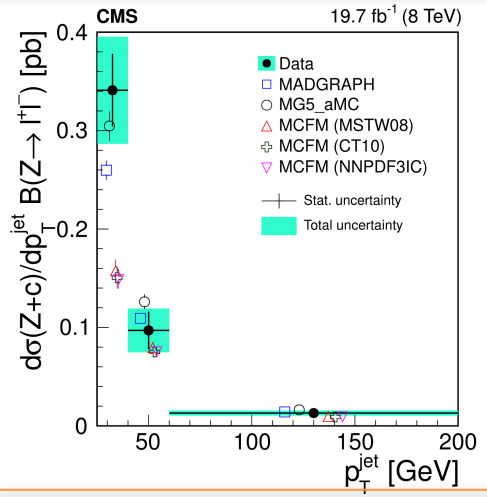
→ Results compatible with neutrino scattering experiments
  → Do not support enhanced strange quark contribution hypothesis

Z + c

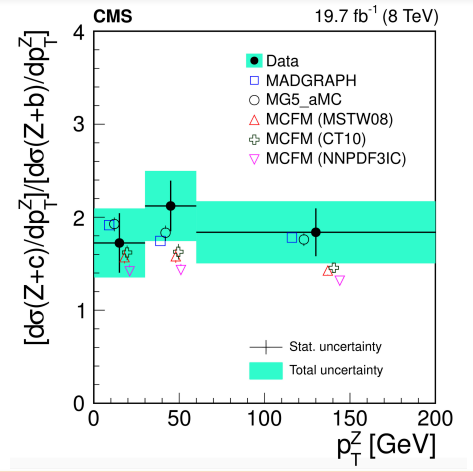
p-p √s=8 TeV
19.8 fb^{-1}

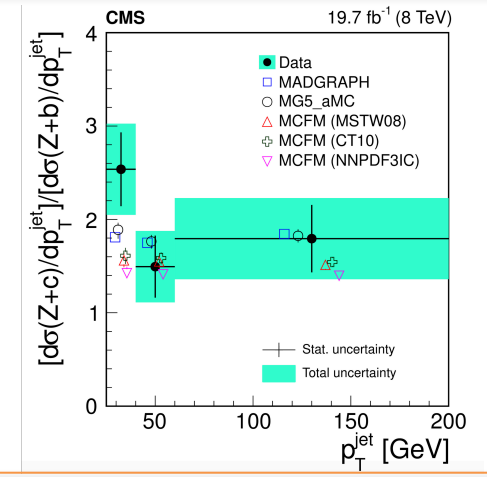
→ Measured Z + c cross section as well as Z+c/Z+b ratio
- → inclusively
- → differentially wrt Z p_T and jet p_T





→ Differential Z+ c cross section results





→ Differential Z+ c/ Z+b cross section results

V (W,Z) + c inclusive results

p-p √s=7,8,13 TeV
5, 19.8,35.7 fb^{-1}

7 TeV

$$\sigma(pp \to W + c + X) \times \mathcal{B}(W \to \mu\nu)(p_T^{\mu} > 25\,\text{GeV}) = 107.7 \pm 3.3\,(\text{stat.}) \pm 6.9\,(\text{syst.})\,\text{pb},$$

$$\sigma(pp \to W + c + X) \times \mathcal{B}(W \to \ell\nu)(p_T^{\ell} > 35\,\text{GeV}) = 84.1 \pm 2.0\,(\text{stat.}) \pm 4.9\,(\text{syst.})\,\text{pb}.$$

$$\frac{\sigma(pp \to W^+ + \bar{c} + X)}{\sigma(pp \to W^- + c + X)}(p_T^{\mu} > 25\,\text{GeV}) = 0.954 \pm 0.025\,(\text{stat.}) \pm 0.004\,(\text{syst.}),$$

$$\frac{\sigma(pp \to W^+ + \bar{c} + X)}{\sigma(pp \to W^- + c + X)}(p_T^{\ell} > 35\,\text{GeV}) = 0.938 \pm 0.019\,(\text{stat.}) \pm 0.006\,(\text{syst.}).$$

13 TeV

NEW

$$\sigma(W + c) = 1026 \pm 31\ (\text{stat})\ ^{+76}_{-72}\ (\text{syst})\,\text{pb},$$

$$\frac{\sigma(W^+ + \bar{c})}{\sigma(W^- + c)} = 0.968 \pm 0.055\ (\text{stat})\ ^{+0.015}_{-0.028}\ (\text{syst}).$$

$$\sigma(pp \to Z+c+X)\mathcal{B}(Z \to \ell^+\ell^-) = 8.8 \pm 0.5\,(\text{stat}) \pm 0.6\,(\text{syst})\,\text{pb}.$$

$$\sigma(pp \to Z+c+X)/\sigma(pp \to Z+b+X) = 2.0 \pm 0.2\,(\text{stat}) \pm 0.2\,(\text{syst}).$$

→ All measurements consistent with SM predictions

SUMMARY

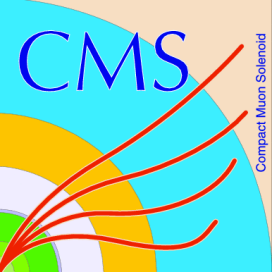
→The measurements provide a detailed description of V+HF production topological structure

- →Testing the validity of QCD
- →Providing confidence in existing MC models for;
  - →Describing SM
  - →Determining BG in BSM searches

→Overall scale good agreement between Data and SM Monte Carlo predictions

→ All CMS SMP public results can be found under the following link:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP

→ More to come; stay tuned!


CMS
Compact Muon Solenoid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THANK YOU!