

# Vector boson production in association with heavy flavor quarks at CMS

Philippe Gras  
On behalf of the CMS collaboration

CEA/IRFU - Saclay

April 21, 14

## Motivations of $V + HF$ production measurements

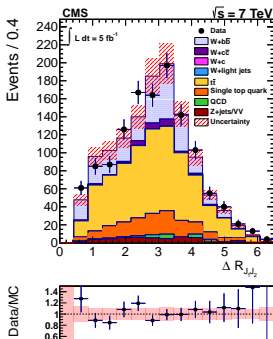
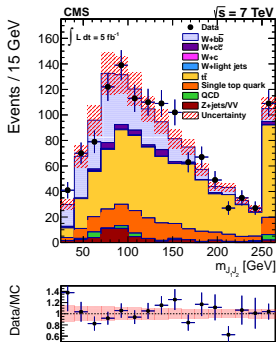
- Test of pQCD.
- Background to Higgs measurement ( $VH$ ,  $H \rightarrow b\bar{b}$ ) and BSM searches.
  - $V + HF$  measurement essential to validate new calculations.
- Heavy quark PDF.
  - strange content, which is poorly known,  $s/\bar{s}$ .
  - exploring charm content with new data and measurement?
- Presented measurements are done in fiducial region with detector effects unfolded.

W + HF

- **Muons:**  $p_T > 25 \text{ GeV}$ ,  $|\eta| < 2.1$   
**Jets:** exactly 2 b-tagged jets with  $p_T > 25 \text{ GeV}$ ,  $|\eta| < 2.4$
- Signal extracted from a fit of  $p_{T,j1}$  in signal region and  $m_{j3j4}$  in  $t\bar{t}$  control sample

$$\sigma \times \mathcal{B}(W \rightarrow \mu\nu) = 0.53 \pm 0.05(\text{stat}) \pm 0.09(\text{syst}) \pm 0.06(\text{theo}) \pm 0.01(\text{lumi}) \text{ pb}$$

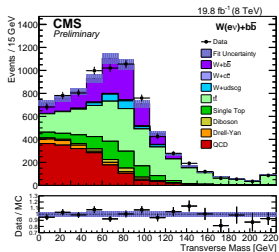
$$\text{MCFM MSTW08} \otimes \text{NP: } 0.55 \pm 0.03 (\text{MCFM}) \pm 0.01 (\text{had.}) \pm 0.05 (\text{DPS}) \text{ pb}$$



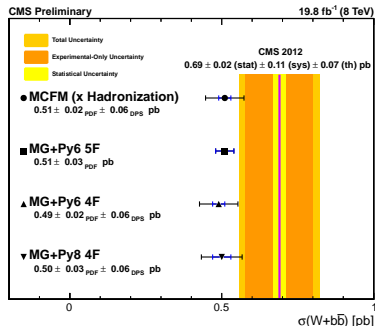
• Good data/theory agreement

PLB 735 (2014) 204

- Combined electron and muon channels
- **Lepton:**  $p_T > 30$  GeV,  $|\eta| < 2.1$  veto on extra leptons with  $p_T > 30$  GeV
- **Jets:** exactly 2 b-tagged jets with  $p_T > 25$  GeV,  $|\eta| < 2.4$
- Signal extracted from a fit of  $m_T$

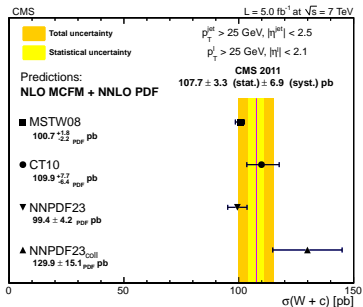


CMS-PAS-SMP-14-020

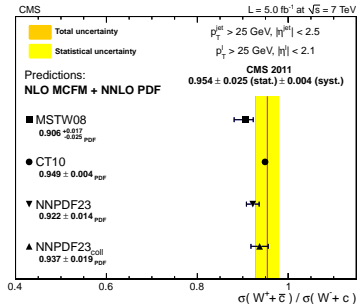


- Agreement with NLO prediction better than  $1 \sigma$

- Sensitive to  $s$  and  $\bar{s}$  PDFs
- Background to  $b/t + E_{T,miss}$
- Cross section, ratio  $W^-c/W^+\bar{c}$ ,  $\eta_1$
- Jets:  $p_T > 25 \text{ GeV}$ ,  $|\eta| < 2.4$
- Leptons.  $\mu$ :  $p_T > 25 \text{ GeV}$ ,  
e and  $e + \mu$  combi:  $p_T > 35 \text{ GeV}$

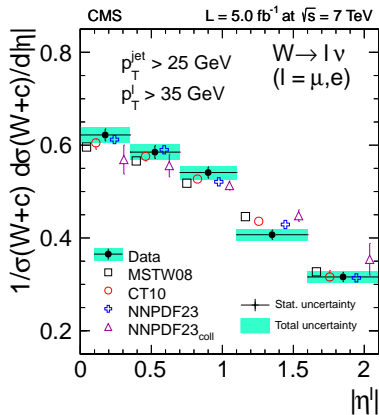
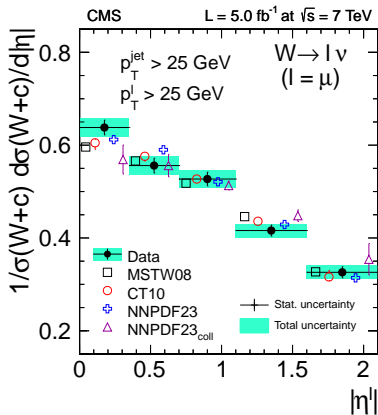


JHEP 02 (2014) 013



- With experimental precision, data show sensitivity to the strange PDF
- With better precision,  $W^-c / W^+\bar{c}$  cross sections will probe the asymmetry in the  $s$ -quark distribution

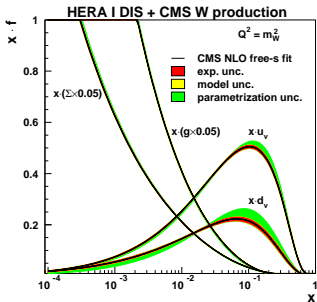
## Lepton pseudorapidity



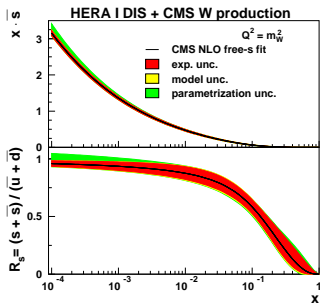
Good agreement observed on total cross section, also on lepton pseudorapidity distribution shape.

# $W_c$ , PDF constraints

- PDF fitted using data from HERA I DIS + CMS  $W$  charge asymmetry (PRD 90, 032004) + CMS  $W_c$  (JHEP 02 (2014) 013), with free strangeness fraction



Gluon, valence and sea distribution  
 $(\Sigma = 2 \cdot (\bar{u} + \bar{d} + \bar{s}))$  at  $Q^2 = m_W^2$



$\bar{s}$  distribution and strange-quark  
 fraction

PRD 90 (2014) 032004



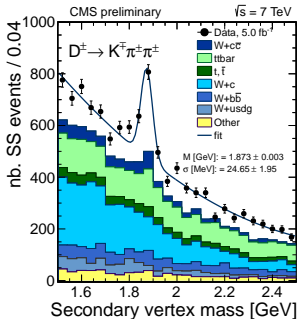
# Wc, data/MC discrepancy in Same-Sign events

$D^\pm$  excess in data/simulation comparison of 3-prong SV mass for **same-sign** W + j events

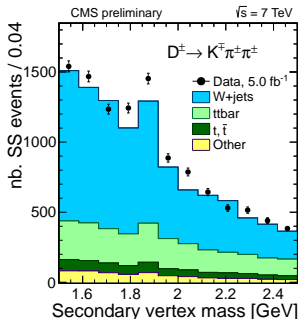
- Cannot come from W + c events
- The measurement is not affected by the discrepancy, as the background is evaluated from OS-SS

Source of the discrepancy?

- Deficit of collinear  $c\bar{c}$  (from gluon splitting), (see R(B,B) in ZBB, slide 12)?
- Better agreement with SHERPA



MADGRAPH + PYTHIA 6



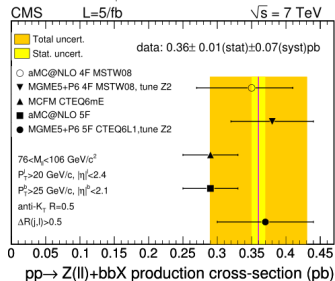
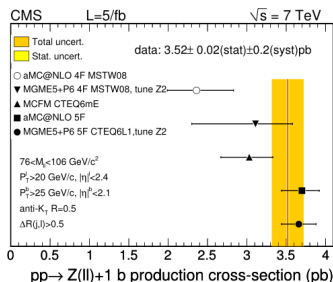
SHERPA 1.3.1

CMS-PAS-SMP-12-002

Z + HF

# Zb, Zbb, 7 TeV

- $\sqrt{s} = 7 \text{ TeV}$ ,  $5 \text{ fb}^{-1}$
- **Leptons:**  $p_T > 20 \text{ GeV}$ ,  $|\eta| < 2.4$     **Z mass window:**  $\pm 15 \text{ GeV}$
- **Jets:**  $p_T > 25 \text{ GeV}$ ,  $|\eta| < 2.5$ ,  $R(l, \text{jet}) > 0.5$   
Both one b-tagged and  $\geq 2$  b-tagged jets

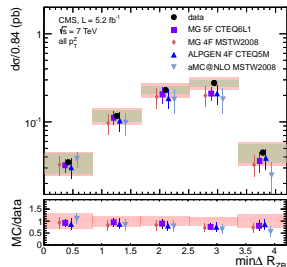
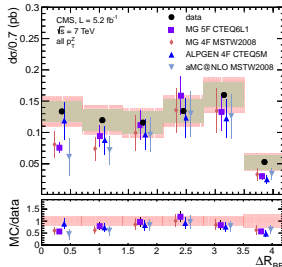
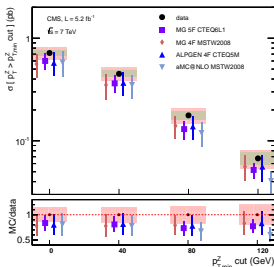


- Z + 1b better described by predictions using five-flavour scheme
- All predictions within  $1\sigma_{\text{exp}}$  for Z + 2b

JHEP 06 (2012) 126

# Zb $\bar{b}$ , angular correlation between b-hadrons, 7 TeV

- $\sqrt{s} = 7 \text{ TeV}$ ,  $5 \text{ fb}^{-1}$
- Reconstructs b-hadrons from tracks and displaced vertices.
  - $\Rightarrow$  **not limited by the jet size** to access to the collinear b's region
- $R(B, B)$ ,  $\Delta\Phi(B, B)$ ,  $\min(R(Z, B))$ ,  $\max R_{ZB}/\min R_{ZB}$  asymmetry  $A_{ZBB}$
- **Leptons:**  $p_T > 20 \text{ GeV}$ ,  $|\eta| < 2.4$  **Z mass window:**  $\pm 10 \text{ GeV}$   
**Two B-hadrons in  $|\eta| < 2.4$ .** ( $p_T$  cut acceptance corrected)

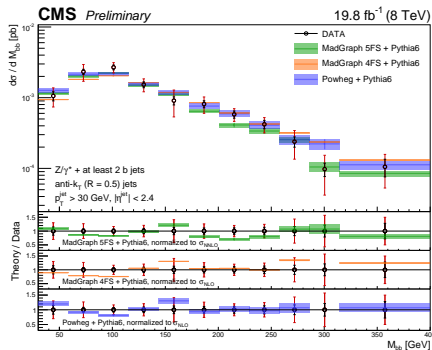


- ALPGEN 4-flavour scheme shows the best agreement.
- Deficit for other predictions in collinear  $R_{BB}$  region.

JHEP 12(2013)  
039

## Measurement

- $\sqrt{s} = 8 \text{ TeV}, 19.8 \text{ fb}^{-1}$
- diff. cross section  $Z + \geq 1 \text{ b}, Z + \geq 2 \text{ b}, \text{ ratios to } Z + \geq 1 \text{ j}, Z + \geq 2 \text{ j}$
- **Leptons:**  $e, \mu, p_T > 20 \text{ GeV}, |\eta| < 2.4$  **Z mass window:**  $\pm 20 \text{ GeV}$   
**b-jets:**  $p_T > 30 \text{ GeV}, |\eta| < 2.4.$  ( $p_T$  cut acceptance corrected)

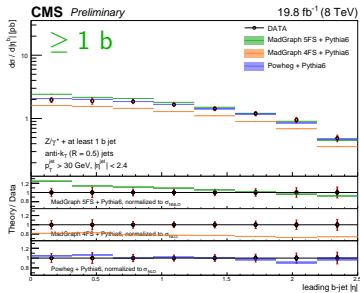
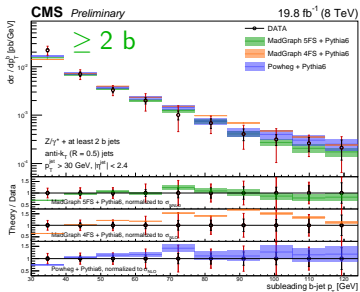
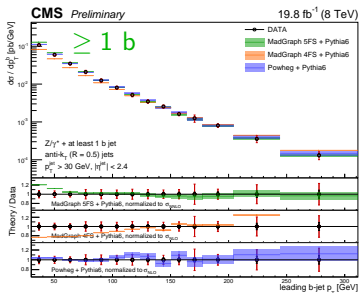


## Comparisons

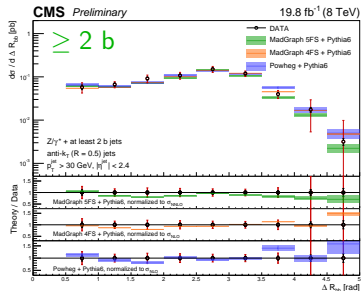
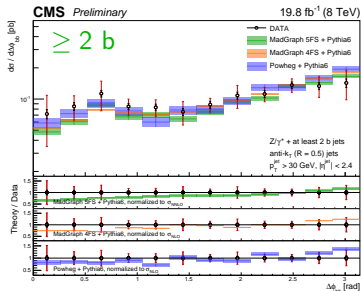
- Madgraph5 5FS ktMLM 0...4 jets + Pythia6 Z2\*, CTEQ6L1,  $\sigma_{\text{tot}}$  normalized to NNLO
- Madgraph5 4FS  $Z + b\bar{b}$  + Pythia6, MSTW08,  $\sigma_{\text{tot}}$  normalized to NLO
- Powheg  $Z + \text{jets}$  NLO + Pythia6, CT10,  $\sigma_{\text{tot}}$  normalized to NLO

CMS-PAS-SMP-14-010

# Zb, Zbb, 8 TeV



- Good agreement with NLO Powheg prediction for  $Z + \geq 1b$
- The three predictions for the  $Z + \geq 2b$  agree with the measurement (larger uncertainties), with a similar degree.



Good agreement with NLO Powheg prediction. Limited by jet size to probe region below  $R(QQ) = 0.5$  as in ZBB measurement.

- Extensive study of  $V+HF$  cross section and kinematics and comparison with latest calculations. Detector response unfolded to allow future comparison with new calculations.
- Indication of deficit in  $V+HF$  production simulation in the region colinear  $Q_s$ .
- 4FS/5FS:
  - importance of new measurement and comparison with 4FS/5FS?
  - when to use 4FS or 5FS?
- Inputs from theory community for new measurements is very important.