GOBIERNO DE ESPAÑA

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

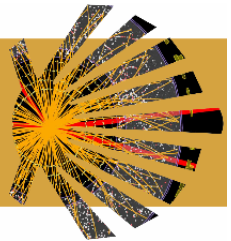
Ciemat

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Selected results on Standard Model Physics at CMS

M.Isabel Josa (CIEMAT-Madrid)

V CPAN Days



Santiago de Compostela

November 26th, 2013

Selected topics

- Concentrate in two analysis that were completed recently with a leadership role of CIEMAT group.

- Measurement of the W-boson helicity in top-quark decays from ttbar production in lepton+jets events in pp collisions at sqrt(s) = 7 TeV. **JHEP 1310 (2013) 167.**
  - Preliminary results already presented in IV CPAN days by Adrián Quintario (link)

- Measurement of associated W + charm production in pp collisions at sqrt(s) = 7 TeV. Submitted for publication in **JHEP.**

Measurement of the W-boson helicity in top-quark decays from ttbar production in lepton+jets events in pp collisions at sqrt(s) = 7 TeV

http://dx.doi.org/10.1007/JHEP10(2013)167

Motivation

- Abundant production of ttbar at LHC
- Top decays almost exclusively to Wb → Possibility for extensive studies of the Wtb vertex
  - W **helicity** in top pair decays: important test of Wtb structure
- Very sensitive to **additional contributions** (BSM or "anomalous") couplings
- W helicity fractions measured from **angular distributions**
- **Lepton + jets ttbar decay mode ($5fb^{-1}$ @ sqrt(s) = 7TeV):**
  - A W decays into a lepton + neutrino and the other W decays hadronically

W helicity in top decays

- W helicity fractions measured from angular distributions:
- cos(θ*): **angle between down-type fermion momentum in W rest frame and W momentum in top rest frame**

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{8}(1+\cos\theta^*)^2 F_R + \frac{3}{4}\sin^2\theta^* F_0$$

In the **SM** (NNLO): $F_0 = 0.687 \pm 0.005$, $F_L = 0.311 \pm 0.005$, $F_R = 0.0017 \pm 0.0001$ ($m_t = 172.8 \pm 1.3$ GeV)

- **Vertex Lagrangian**

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^\mu(V_L P_L + V_R P_R)tW_\mu^- - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_\nu}{M_W}(g_L P_L + g_R P_R)\,t\,W_\mu^- + \text{H.c.}$$

- In the SM: $V_L = V_{tb} \cong 1$; V_R, g_L, g_R are all =0
- **Straightforward to interpret fractions in terms of anomalous couplings**

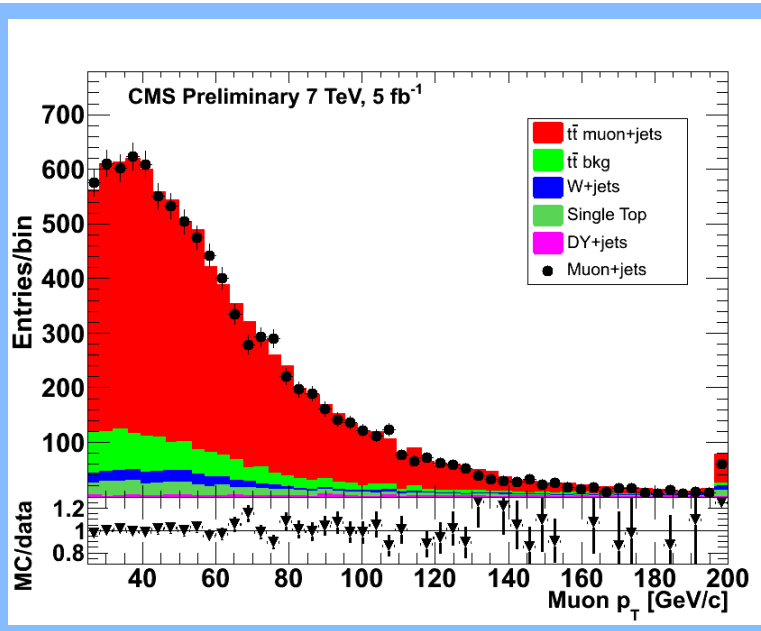
Analysis Summary

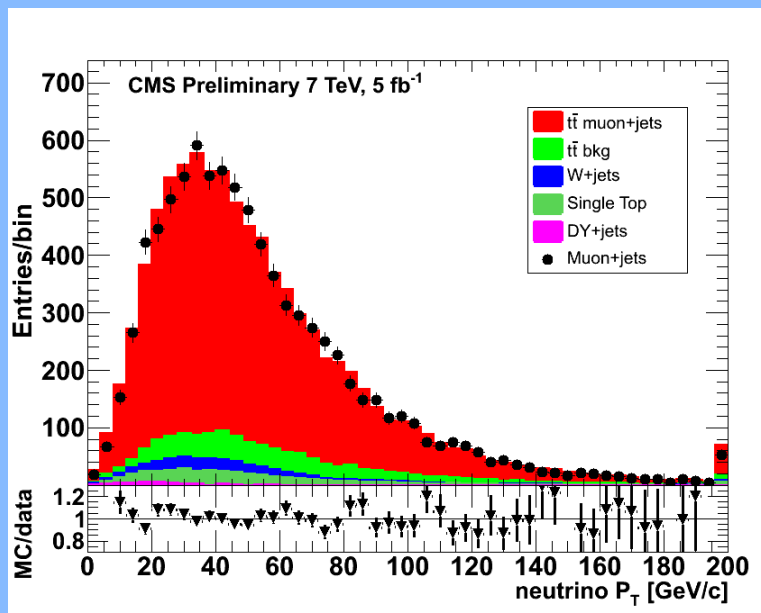
- Standard CMS semileptonic top selection:
  - Single muon/electron+hadronic activity triggers
  - High p_T and isolated lepton:

    $p_T(\mu)>25$ GeV, $p_T(e)>30$ GeV
  - $|\eta(\text{lepton})| < 2.1$
  - High Transverse mass:

    30 GeV < M_T(l, MET)<200 GeV

- Jet reconstruction:
  - Anti-k_T, $\Delta R = 0.5$, $p_T(\text{jet}) > 30$ GeV, $|\eta(\text{jet})|<2.5$
  - At least 4 jets
  - At least two of them b-tagged (CSV)





Ttbar system reconstruction

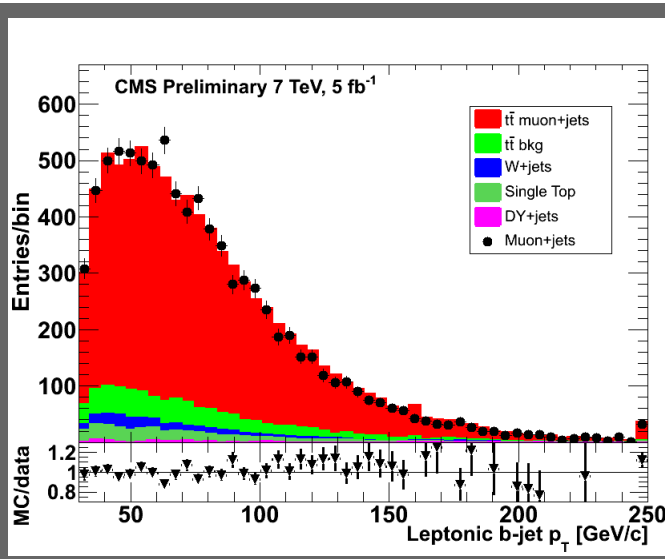
- **Jet combination:** *test all jets passing cuts as b-jets (t_{lep}, t_{had}), light-jets (W_{had})*

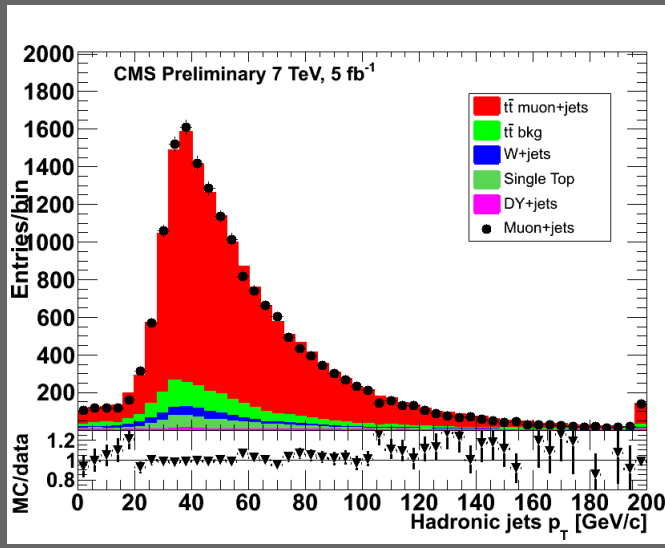
$$\chi^2_{comb} = \left(\frac{m_t - m_t^{ref}}{\sigma_{m_t}}\right)^2 + \left(\frac{m_{\bar{t}} - m_t^{ref}}{\sigma_{m_{\bar{t}}}}\right)^2 + \left(\frac{M_W^{lep} - 80.4}{\sigma_{M_W^{lep}}}\right)^2 + \left(\frac{M_W^{had} - 80.4}{\sigma_{M_W^{had}}}\right)^2 - \sum_{i=1,4} 2\ln p_i(disc|f),$$

Correct association in 71%.

- **Kinematic fitter:** *improve reconstruction of ttbar system for the best combination (improve determination of helicity angle)*

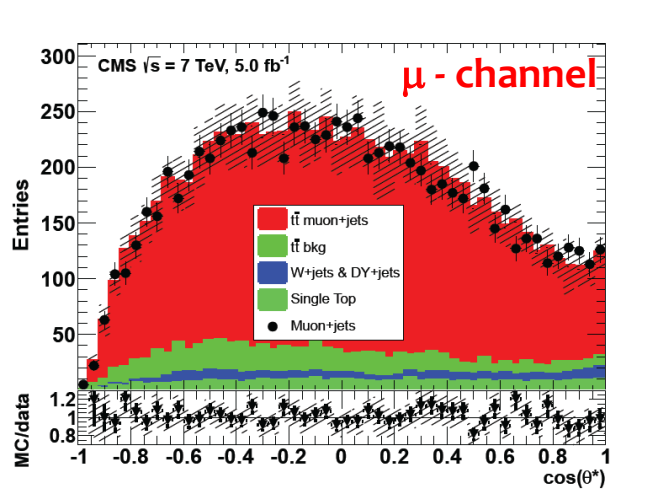
$$\chi^2 = \left(\frac{m_t - m_t^{ref}}{\sigma_{m_t}}\right)^2 + \left(\frac{m_{\bar{t}} - m_t^{ref}}{\sigma_{m_{\bar{t}}}}\right)^2 + \left(\frac{M_W^{lep} - 80.4}{\sigma_{M_W^{lep}}}\right)^2 + \left(\frac{M_W^{had} - 80.4}{\sigma_{M_W^{had}}}\right)^2 + \sum_i \left(\frac{p_i^{fit,lep} - p_i^{lep}}{\sigma_{p_i^{lep}}}\right)^2 + \sum_j \sum_i \left(\frac{p_i^{fit,jet_j} - p_i^{jet_j}}{\sigma_{p_i^{jet_j}}}\right)^2,$$



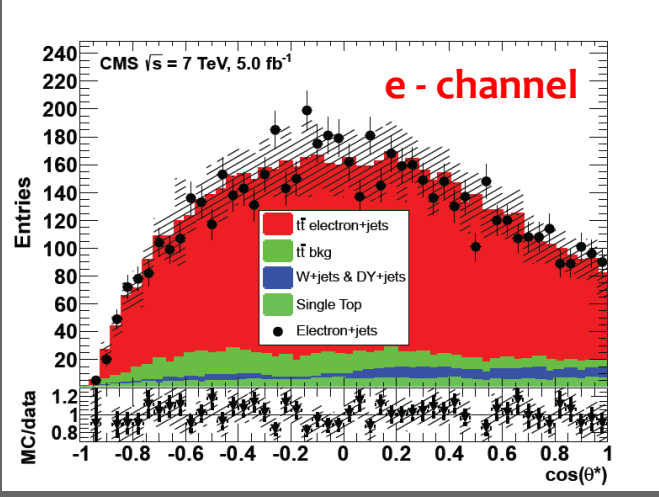


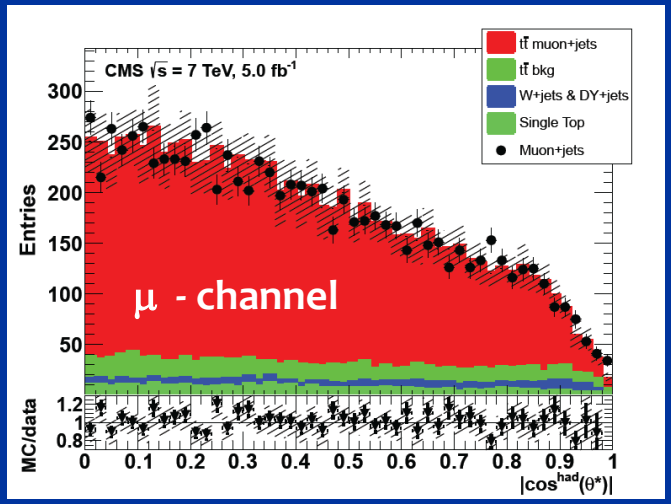
Main Backgrounds: *ttbar from fully-leptonic or hadronic decays, W+jets, s-top, DY+jets (MC + Data driven estimations)*

Helicity Angle distributions

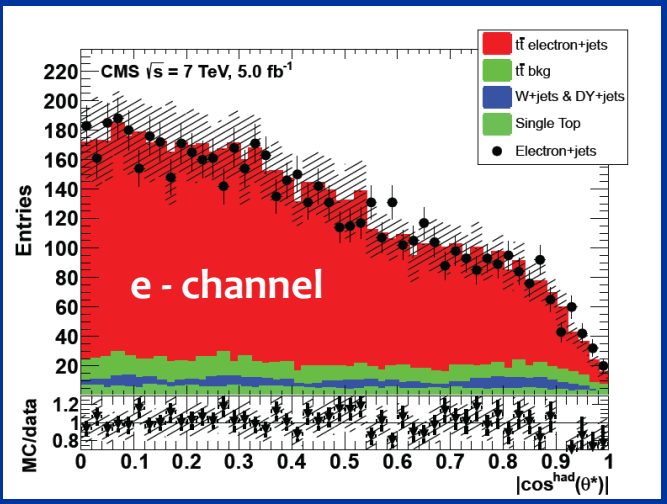


Agreement between data and predictions with SM fractions





Hadronic side: absolute value



Extraction of Helicity fractions

- Likelihood fit to the experimental cos(θ*) distribution

$$\mathcal{L}(\vec{F}) = \prod_{bin\ i} \frac{N_{MC}(i;\vec{F})\, N_{data}(i)}{(N_{data}(i))!} \exp\left(-N_{MC}(i;\vec{F})\right)$$

$$\begin{aligned} N_{\mathrm{MC}}(i,\vec{F}) &= N_{\mathrm{BKG}}(i) + N_{\mathrm{t\bar{t}}}(i;\vec{F}), \\ N_{\mathrm{t\bar{t}}}(i;\vec{F}) &= \mathcal{F}_{\mathrm{t\bar{t}}} \left[\sum_{\mathrm{t\bar{t}\ events}} W(\cos\theta^*_{\mathrm{gen}}(i);\vec{F}) \right], \\ N_{\mathrm{BKG}}(i) &= N_{\mathrm{W+jets}}(i) + N_{\mathrm{DY+jets}}(i) + N_{\mathrm{single-top}}(i) + \mathcal{F}_{\mathrm{t\bar{t}}} \times N_{\mathrm{t\bar{t}\ non-\ell+jets}}(i) \end{aligned}$$

- Number of expected ttbar events for different helicity configurations $\vec{F}$ obtained by reweighting

$$W(\cos\theta^*_{gen};\vec{F}) \equiv \frac{\rho(\cos\theta^*_{gen})}{\rho^{SM}(\cos\theta^*_{gen})} = \frac{\frac{3}{8}F_L(1-\cos\theta^*_{gen})^2 + \frac{3}{4}F_0\sin^2\theta^*_{gen} + \frac{3}{8}F_R(1+\cos\theta^*_{gen})^2}{\frac{3}{8}F_L^{SM}(1-\cos\theta^*_{gen})^2 + \frac{3}{4}F_0^{SM}\sin^2\theta^*_{gen} + \frac{3}{8}F_R^{SM}(1+\cos\theta^*_{gen})^2}$$

Extraction of Helicity fractions

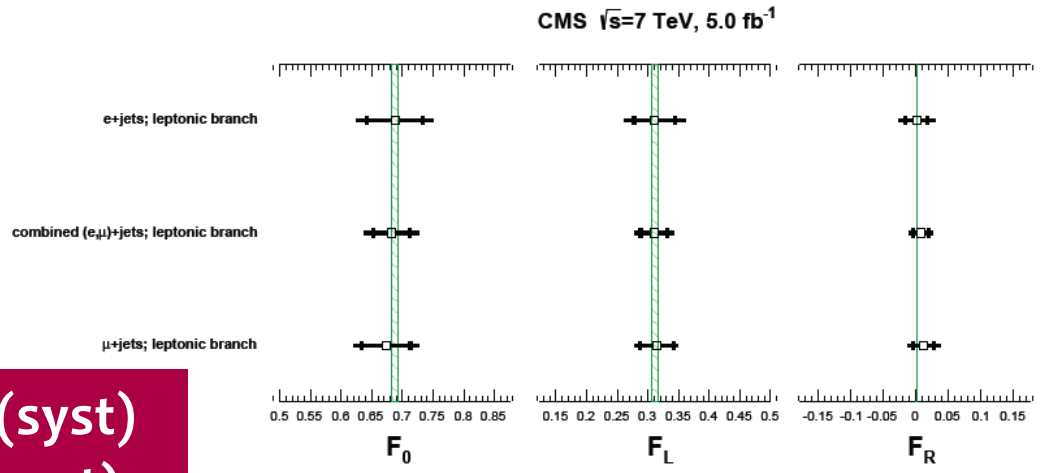
- Use hadronic or leptonic side of the event (or both together)
- Unitarity condition: $F_L + F_R + F_0 = 1$
  - in all measurements
  - **measure F_0, F_L,** retrieve **F_R** from F_0,F_L (3D fits)
- Since in SM **F_R ~0 -> try also measure F_0, keep F_R =0** (2D fits)

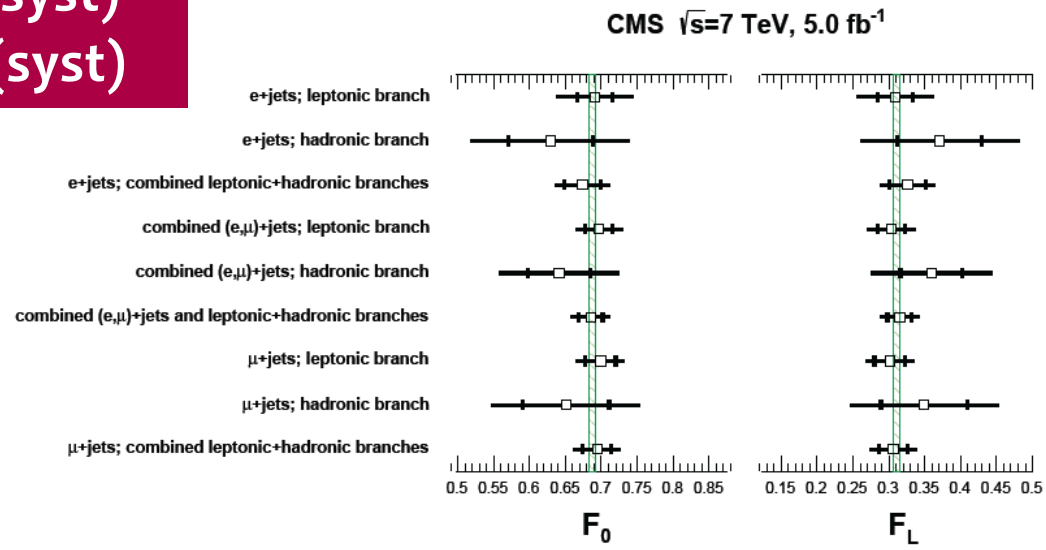
- Hadronic histograms 'sums up' $\cos_{had}(\theta^*) \sim +1$ (F_R) and ~ -1 (F_L) regions: poor contribution in 3D fits

Results

Measurements from 2D and 3D fits consistent and with SM prediction (NNLO in green)

$F_0 = 0.682 \pm 0.030\,(stat) \pm 0.033\,(syst)$
$F_L = 0.310 \pm 0.022\,(stat) \pm 0.022\,(syst)$
$F_R = 0.008 \pm 0.012\,(stat) \pm 0.014\,(syst)$





Systematic uncertainties:

Leptonic side: dominated by W+jets bkg and signal modeling (both Q^2 and top mass)

Hadronic side (only 2D fits): W+jets; jet resol./scale become important

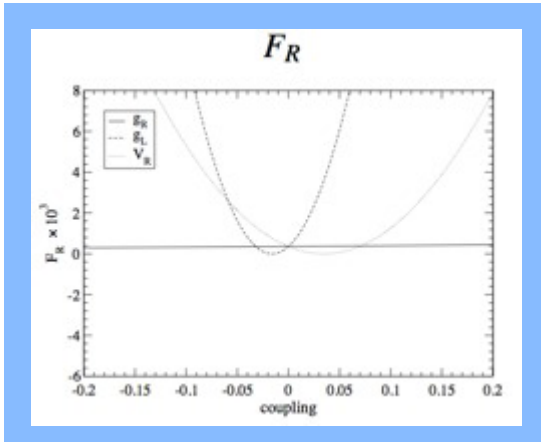
Results

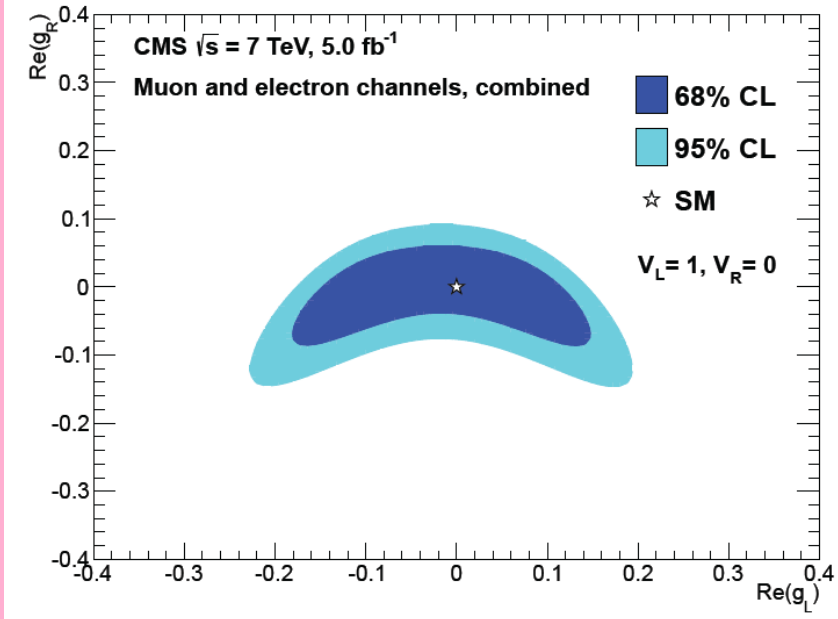
- Fix V_L=1 and V_R=0 (SM predictions)

1) fix also g_L=0 and set limits on g_R
   - F_R does not depend on g_R.
   - Derive limits on g_R from F_0.
   - Use 2D fit (setting F_R=0, more precise F_0).

$Re(g_R) = -0.008 \pm 0.024$ (stat) ± 0.030 (syst)

2) set limits on $Re(g_R)$ vs $Re(g_L)$ from F_0, F_L values.



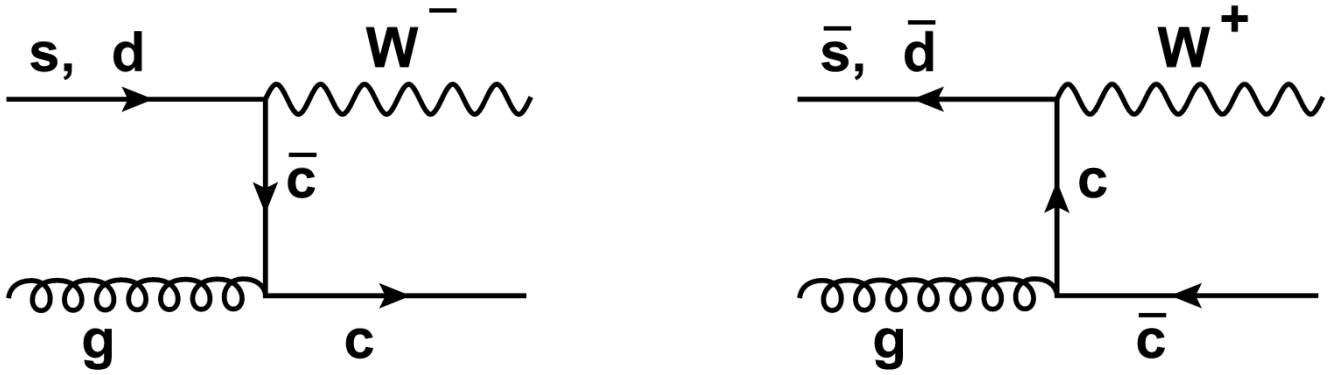


Measurement of associated W + charm production in pp collisions at sqrt(s) = 7 TeV

Submitted to JHEP (http://arxiv.org/abs/1310.1138)

Motivation

- The study of associated W plus charm quark production at hadron colliders provides direct access to the **strange quark content** of the proton at the electroweak scale→ help reducing the uncertainties on the strange parton distribution function



- Other contributions (g+d-quark) are small (few %)
- **Total and differential** W+c **cross sections** and **charge cross-section ratio** $\sigma(W^{+}+\bar{c})/\sigma(W^{-}+c)$

Analysis Summary

- Standard CMS W selection:
  - Single muon/electron triggers
  - High p_T and isolated lepton:

    $p_T(\mu)>25$ GeV, $p_T(e)>35$ GeV
  - High Transverse mass:

    $M_T(\mu, MET)>40$ GeV, $M_T(e,MET)>55$ GeV
  - $|\eta(lepton)| < 2.1$
- Jet reconstruction:
  - Anti-k_T, $\Delta R = 0.5$, $p_T(jet) > 25$ GeV, $|\eta(jet)|<2.5$
- c-tagging:
  - Exclusive and inclusive reconstruction of D meson decays: $c^{\pm} \rightarrow D^{\pm}$, $c^{\pm} \rightarrow D^{*\pm} \rightarrow D^0+\pi^{\pm}$, $c^{\pm} \rightarrow l^{\pm}$

- Standard CMS W selection:
  - Single muon/electron triggers
  - High p_T and isolated lepton:

    $p_T(\mu)>25\ (35)$ GeV, $p_T(e)>35$ GeV
  - High Transverse mass:

    $M_T(\mu, MET)>40$ GeV, $M_T(e,MET)>55$ GeV
  - $|\eta(lepton)| < 2.1$
- Jet reconstruction:
  - Anti-k_T, $\Delta R = 0.5$, $p_T(jet) > 25$ GeV, $|\eta(jet)|<2.5$
- c-tagging:
  - Exclusive and inclusive reconstruction of D meson decays: $c^{\pm}\rightarrow D^{\pm}$, $c^{\pm}\rightarrow D^{*\pm}\rightarrow D^0+\pi^{\pm}$, $c^{\pm}\rightarrow l^{\pm}$

Analysis Summary

In **W+c events** the charge of the **W** (and the lepton) and the charge of the **c quark** are of **opposite sign.**

The **charge of the c quark is unequivocally determined** in the three signatures ($c^{\pm}\rightarrow D^{\pm}$, $c^{\pm}\rightarrow D^{*\pm}\rightarrow D^0+\pi^{\pm}$, $c^{\pm}\rightarrow l^{\pm}$)

OS events = sign(W) × sign(c) < 0

SS events = sign(W) × sign(c) > 0

➡ **OS-SS selection**

Main bck. contribute equally to OS and SS (including gluon splitting)

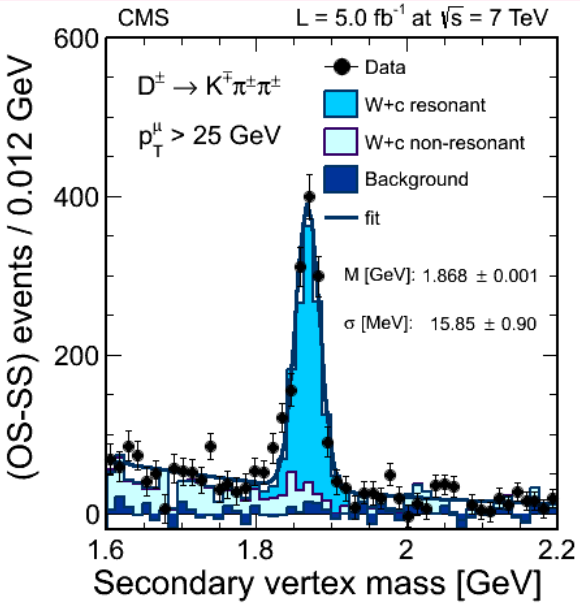
→ **Subtracted**

Clean samples after subtraction

$D^{\pm} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}$

Events with a Secondary Vertex with 3 tracks

Signal Region: events in the $|m^{REC}-1.87|<0.05$ GeV window



$D^{*}(2010)^{\pm} \rightarrow D^{0}\,\pi^{\pm} \rightarrow K^{\mp}\pi^{\pm}\,\pi^{\pm}$

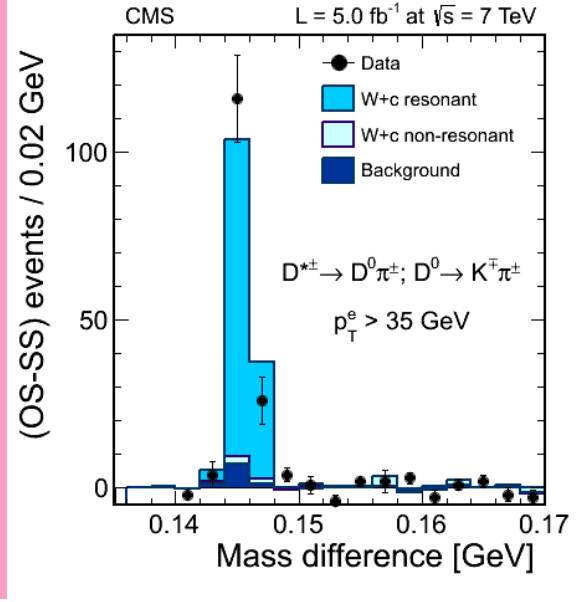
Events with a SV with 2 tracks. The SV is combined with a PV track

M_{SV} compatible with D^0:

$|M_{SV}-1.864|<0.07$ GeV

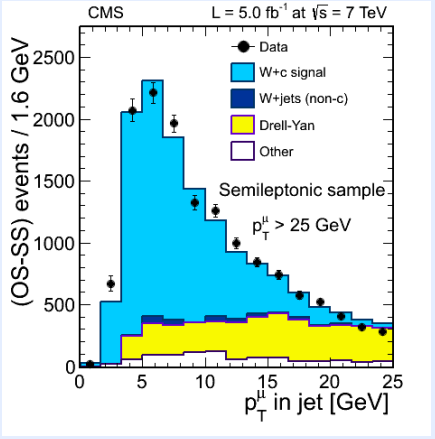
Signal Region:

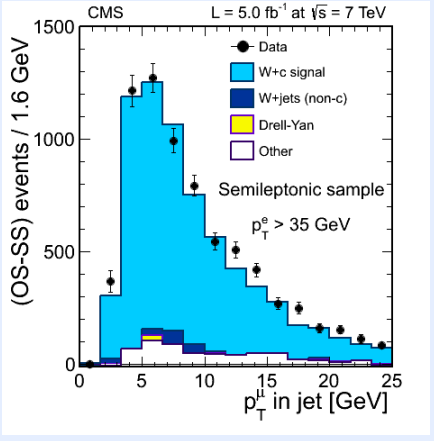
$|m_{D^*}-m_{D^0}-145|<5$ MeV



Semileptonic ($c^{\pm} \rightarrow \mu^{\pm}$)

Events with an Identified muon within the jet





W+c total cross section

$$\sigma(W+c) = \frac{N_{sel} - N_{bkg}}{\mathcal{L}_{int}\,\mathcal{B}\,\mathcal{A}\,\epsilon}$$

- Fiducial region:
  - Charm quark: $p_T(c) > 25$ GeV, $|\eta(c)| < 2.5$
  - W→ l nu: p_T(lepton) > 25 (35) GeV, $|\eta$(lepton)$| < 2.1$
- Acceptance × efficiency:
  - Reference Monte Carlo: Madgraph+Pythia + Base PDF: MSTW08NNLO
  - Corrected for detector effects
- Charm branching fractions from LEP
- Good agreement among different subchannels

$\sigma(W+c) \times BR(W\to l\nu) = 107.7 \pm 3.3\ (stat) \pm 6.9\ (syst)$ pb $[p_T(l) > 25$ GeV$]$

$\sigma(W+c) \times BR(W\to l\nu) = 84.1 \pm 2.0\ (stat) \pm 4.9\ (syst)$ pb $[p_T(l) > 35$ GeV$]$

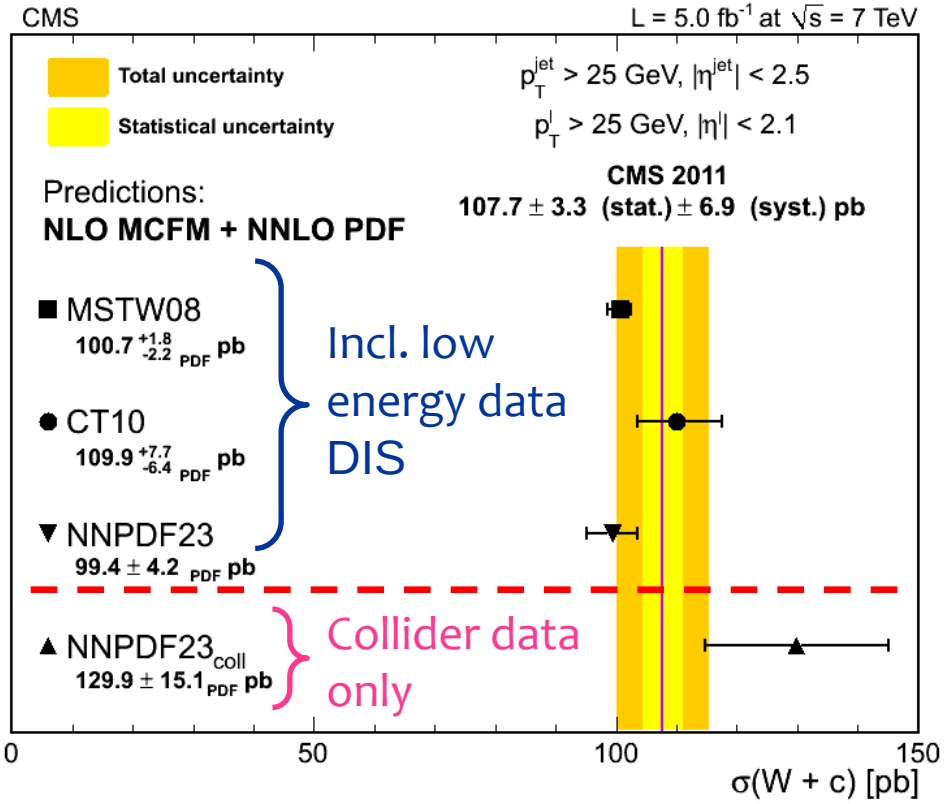
Systematic uncertainties (~6%):
Charm BR, Jet energy scale, MC statistics, Vertex reconstruction, Muon eff. Inside jets …

Comparison with theory

- MCFM v6.1 at **NLO** E_T(c-jet) > 25 GeV, |η(c-jet)|<2.5, ΔR = 1
- **MSTW08, CT10, NNPDF2.3, NNPDF2.3$_{collider}$** (all at **NNLO**)

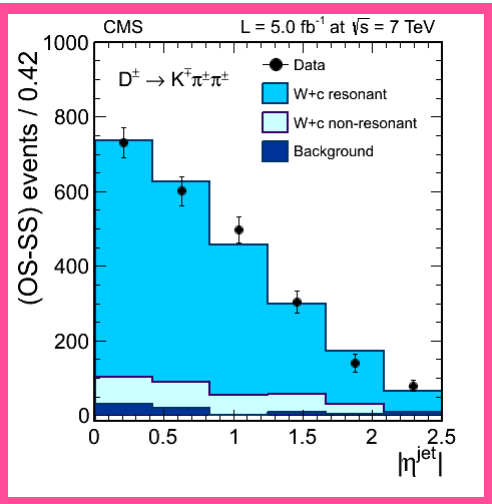
- Data agree with predictions using PDF sets that include low energy DIS data (predict a strange suppression wrt other light quarks)

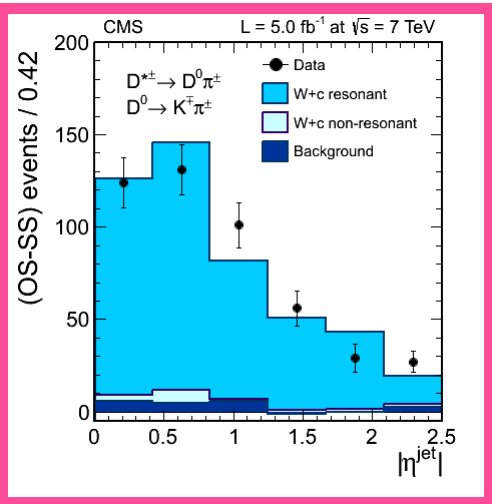
- PDF with collider data only: predict a symmetric light sea, but with large uncertainty. In agreement with data within 1 σ

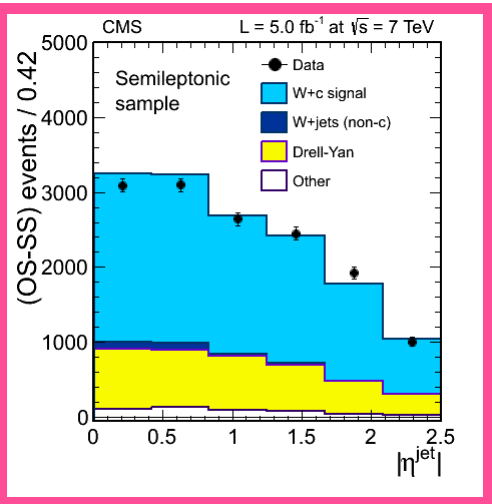


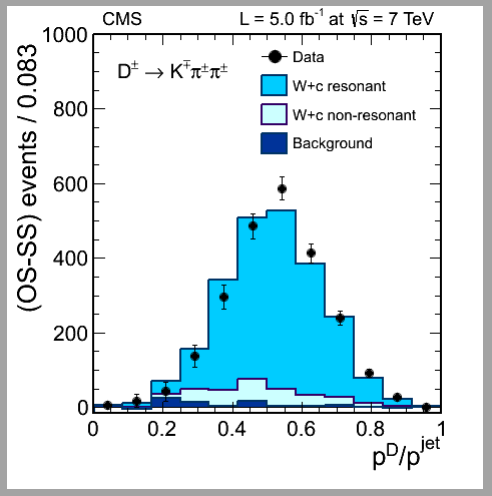
Same observations for p_T(lepton)> 35 GeV

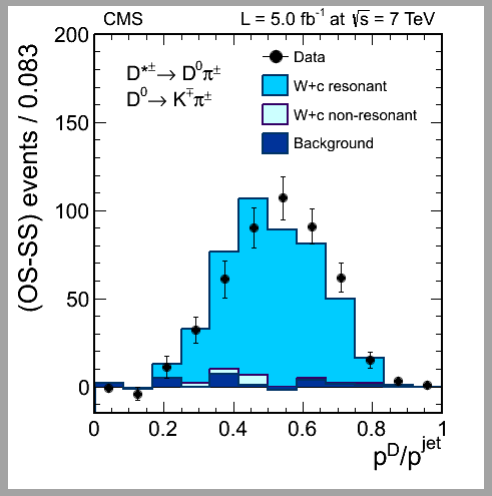
Characterization of the kinematics of W+c events

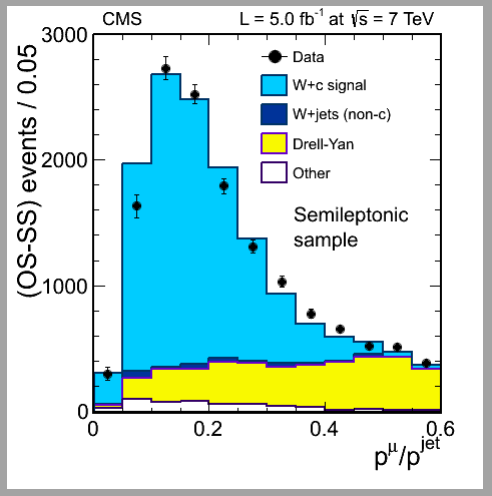








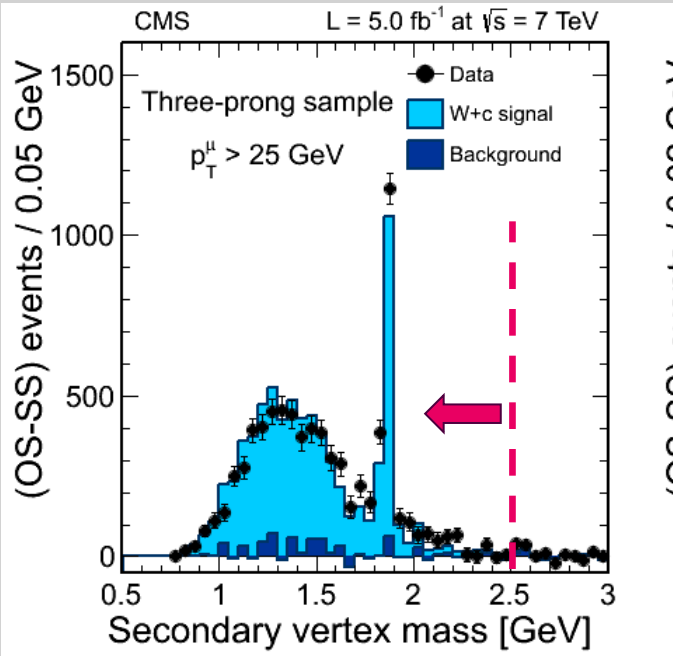


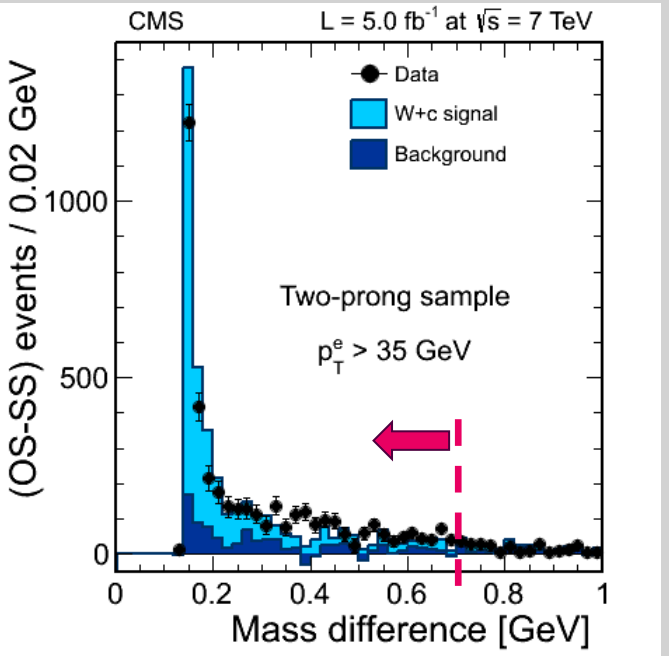


Overall good agreement/**Slightly harder fragmentation** spectra in data than in MC

W+c normalized differential cross-sections

- **Differential wrt pseudorapidity of the lepton from the W decay**
- **Relative measurement** → Cancellation of efficiencies & other systematic uncertainties in the ratio (statistical uncertainties dominate).





Inclusive selection

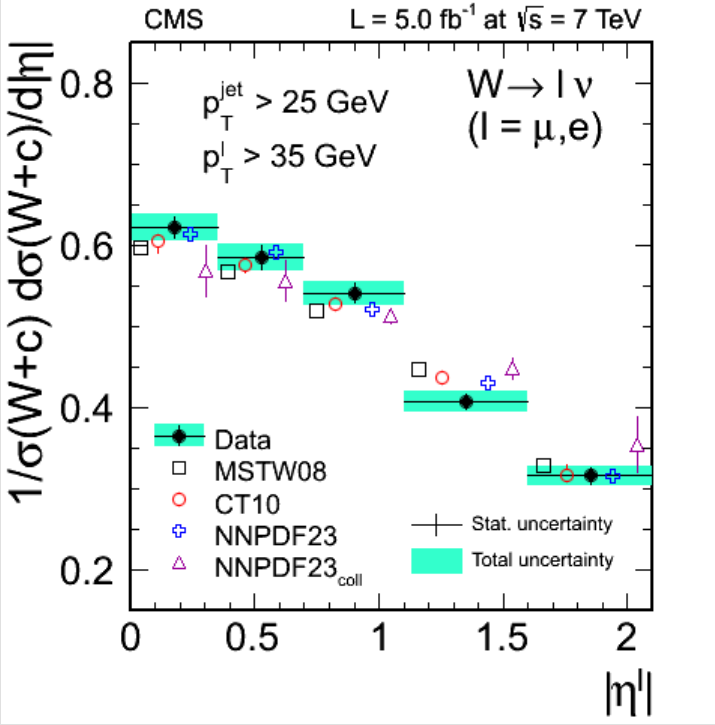
- Not focused on resonances, broader phase-space
- Release selection criteria
- Enlarge statistics

W+c differential cross sections

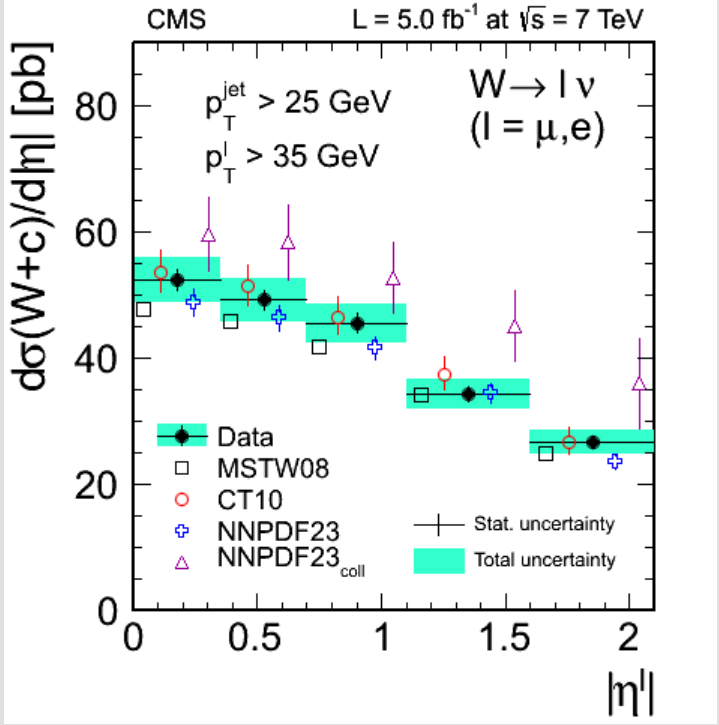
Agreement among different **subchannels** and **muons** and **electrons** → combine

Normalize with the total cross section → absolute diff. cross section

Normalized differential cross section



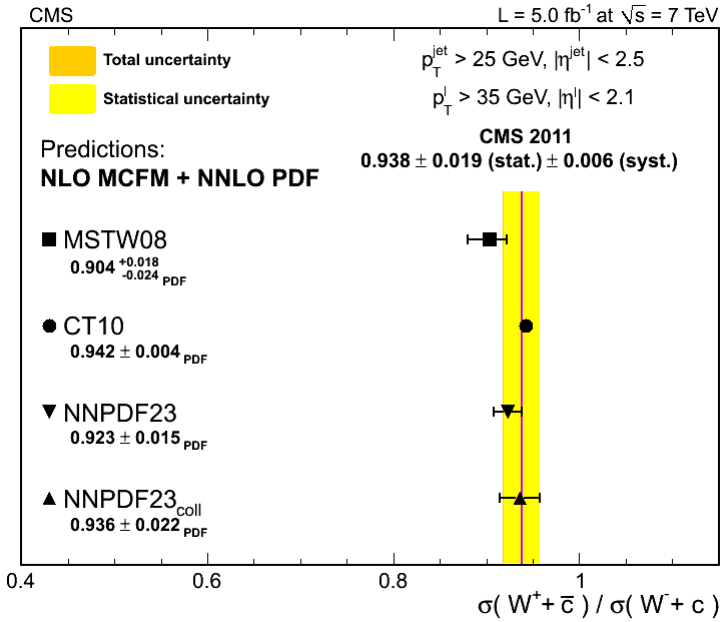
Absolute differential cross section

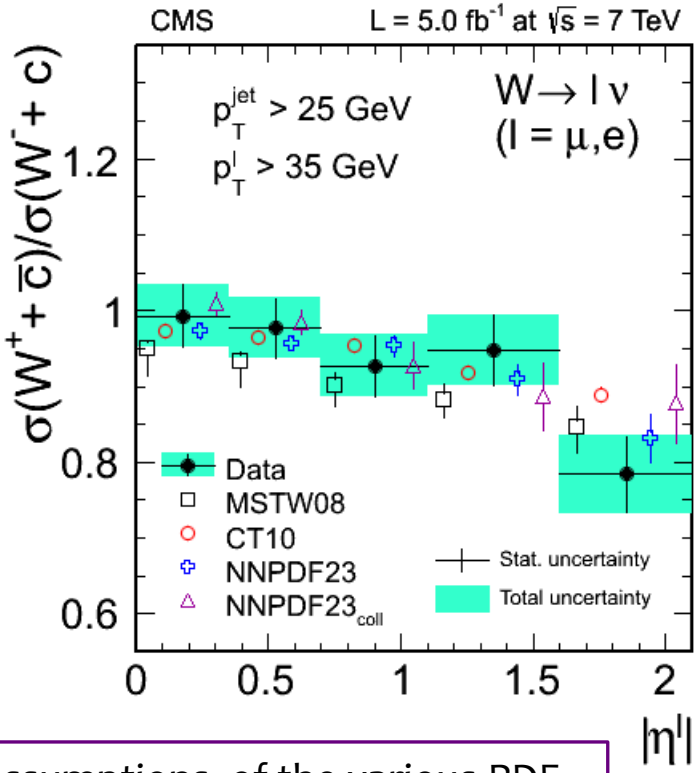


Charged cross section ratio

- **Total** and wrt **pseudorapidity** of the **lepton** from the W decay
- **Inclusive selection**
- **Relative measurement:** Cancellation of syst. uncertainties in the ratio (lepton reco.), statistical uncertainties dominate.

$$R_c^{\pm} = \frac{\sigma(W^+ + \bar{c})}{\sigma(W^- + c)} = \frac{(N_{sel}^+ - N_{bkg}^+)}{(N_{sel}^- - N_{bkg}^-)}$$





Different assumptions of the various PDF groups (ex. **s^+ = s+sbar** and **s^- = s-sbar**)

Conclusions and outlook

- **Top:**
  - Most accurate determination of **W-helicity** fractions in top decays.
  - Stringent limits on anomalous **Wtb vertex** couplings.
  - Working now on the analysis at 8 TeV.
  - CIEMAT involvement in the **Top LHC WG** for combination of helicity measurements with ATLAS
- **V+HF:**
  - First step towards an improved determination of quark PDFs
  - Improved W+c → s-pdf
  - Z+c → c-pdf

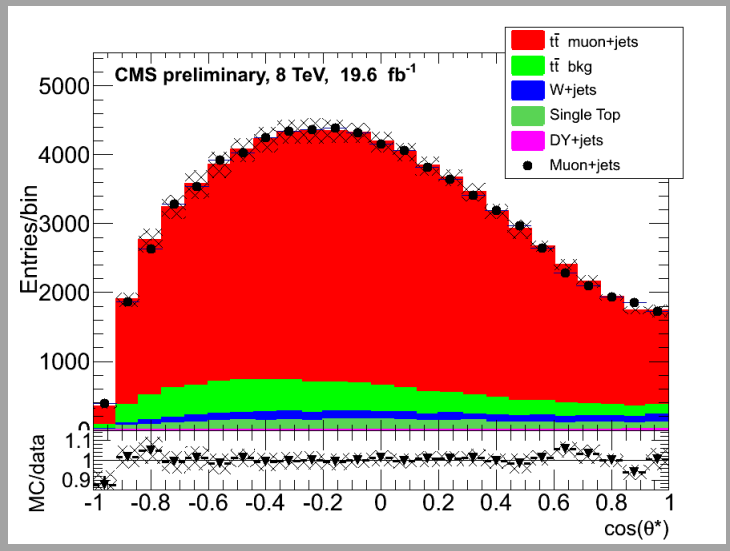
Thank you for your attention !!

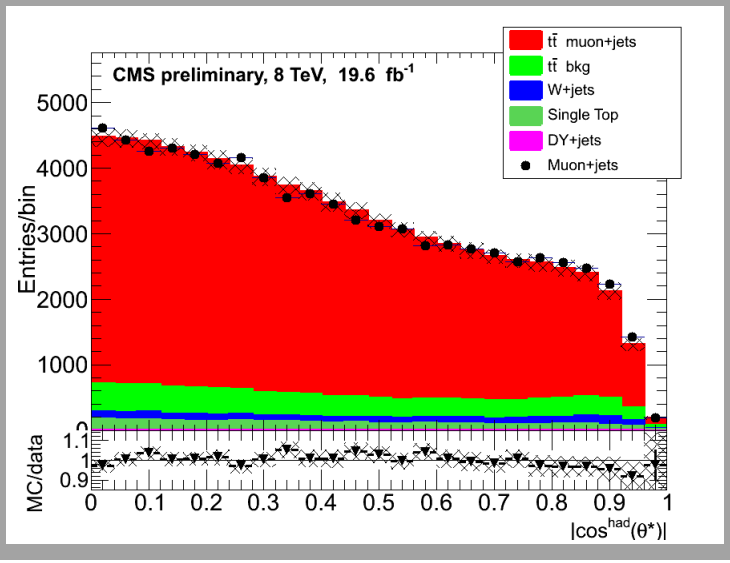
New results at sqrt(s) = 8 TeV

- Preliminary results from 2012 data set: 19.6 pb^{-1} of pp collisions at 8 TeV. Muon channel only.
- Increase in ttbar cross section wrt 7 TeV larger than that of main backgrounds (W+jets)
- Reduced uncertainties
- Agreement with the Standard Model

$F_0 = 0.659 \pm 0.015\ (stat) \pm 0.023\ (syst)$
$F_L = 0.350 \pm 0.010\ (stat) \pm 0.024\ (syst)$

Unitarity condition ($F_L + F_R + F_0 = 1$) →
$F_R = -0.009 \pm 0.006\ (stat) \pm 0.020\ (syst)$





CMS-TOP-13-008 http://cds.cern.ch/record/1601030

Systematic uncertainties in 3D fits

Systematic Uncertainties	μ+jets ($\cos\theta^*$)			e+jets ($\cos\theta^*$)			ℓ+jets ($\cos\theta^*$)		
	3D fit		2D fit	3D fit		2D fit	3D fit		2D fit
	$\pm\,\Delta F_0$	$\pm\,\Delta F_L$	$\pm\,\Delta F_0$	$\pm\,\Delta F_0$	$\pm\,\Delta F_L$	$\pm\,\Delta F_0$	$\pm\,\Delta F_0$	$\pm\,\Delta F_L$	$\pm\,\Delta F_0$
JES	0.005	0.003	0.001	0.006	0.002	0.003	0.006	0.003	0.001
JER	0.009	0.005	0.001	0.014	0.009	0.003	0.011	0.007	0.001
Lepton eff.	0.001	0.001	0.001	0.009	0.012	0.015	0.001	0.002	0.002
b-tag eff.	0.001	0.001	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	0.001	0.001	$< 10^{-3}$	$< 10^{-3}$
Pileup	0.013	0.011	0.008	0.008	0.007	0.005	0.002	$< 10^{-3}$	0.008
Single-t bkg.	0.004	$< 10^{-3}$	0.003	0.004	$< 10^{-3}$	0.004	0.004	0.001	0.003
W+jets bkg.	0.019	0.007	0.006	0.009	0.006	0.022	0.013	0.004	0.006
DY+jets bkg.	0.002	0.001	0.001	0.001	$< 10^{-3}$	0.001	0.001	$< 10^{-3}$	0.001
MC statistics	0.016	0.012	0.009	0.019	0.015	0.012	0.016	0.012	0.010
Top-quark mass	0.011	0.008	0.007	0.025	0.018	0.014	0.016	0.011	0.019
$t\bar{t}$ scales	0.013	0.009	0.007	0.015	0.018	0.030	0.009	0.009	0.011
$t\bar{t}$ match. scale	0.004	0.001	0.006	0.010	0.013	0.016	0.011	0.010	0.008
PDF	0.002	0.001	0.003	0.004	0.002	0.002	0.002	$< 10^{-3}$	0.003

Systematic uncertainties in 2D fits

	μ+jets ($\lvert\cos^{\text{had}}\theta^*\rvert$)	e+jets ($\lvert\cos^{\text{had}}\theta^*\rvert$)	ℓ+jets ($\lvert\cos^{\text{had}}\theta^*\rvert$)
Systematic	2D fit	2D fit	2D fit
Uncertainties	$\pm\ \Delta F_0$	$\pm\ \Delta F_0$	$\pm\ \Delta F_0$
JES	0.010	0.008	0.002
JER	0.042	0.032	0.038
Lepton eff.	0.002	0.002	0.001
b-tag eff.	0.003	$< 10^{-3}$	0.002
Pileup	0.018	0.006	0.015
Single-t bkg.	0.005	0.007	0.006
W+jets bkg.	0.060	0.050	0.040
DY+jets bkg.	0.002	0.005	0.002
MC statistics	0.023	0.028	0.025
Top-quark mass	0.008	0.041	0.014
$t\bar{t}$ scales	0.022	0.033	0.027
$t\bar{t}$ match. scale	0.002	0.035	0.013
PDF	0.013	0.014	0.014

Systematic uncertainties on W+c total cross section

Source	$p_T^\mu > 25$ GeV $\Delta_{syst}[\%]$	$p_T^\ell > 35$ GeV $\Delta_{syst}[\%]$
MC statistics	1.6	1.3
Lepton efficiency, resolution	0.8	1.5
Muon efficiency in charm decay	1.4	1.5
Vertex reconstruction	1.8	1.7
Pileup	0.9	0.8
Jet energy scale	3.0	1.7
$\not{E}_T$	2.0	2.0
$\mathcal{B}(c \to D^\pm \to K^\mp \pi^\pm \pi^\pm)$	1.5	1.5
$\mathcal{B}(c \to D^{*\pm}(2010) \to D^0 \to K^\mp \pi^\pm)$	0.7	0.6
$\mathcal{B}(c \to \ell)$	2.6	2.7
ISR and Q^2-matching	0.2	0.2
Fragmentation function	0.8	0.6
Other theory uncertainties on $\mathcal{A}\,\epsilon$	0.8	0.7
DY background	1.4	0.9
Luminosity	2.2	2.2
Total	6.3	5.7

Systematic Uncertainties on differential cross section

- Most of the effects cancel in the ratio.

	Normalized Diff Xsec.
MC statistics	3-5%
Muon Momentum Scale and Resolution	0.2-0.4%
Electron Momentum Scale and Resolution	1(B)%-1.5%(E)
Muon Reco&ID	0.35%
Electron Reco&ID	0.25%
Background subtraction	0.3%

- Other systematic uncertainties (MET, PileUp Reweighting, Jet Scale and resolution, PDF uncertainties, Charm fragmentation) have been found to have no effect on the ratios
- Statistical error: 5 - 7% → **Normalized diff. measurement dominated by statistical uncertainties**

Systematic uncertainties in the cross section ratio

- Mainly from effects on the lepton reconstruction
- Background neglection

	Charge Ratio
Muon Momentum Scale and Resolution	0.4-0.8% (0.2-0.3% incl.)
Electron Momentum Scale and Resolution	1(B)%-1.5%(E)
Background neglection (2 and 3 prongs vtx)	0.3-0.2 % (incl.)
Background neglection (semileptonic)	1% (W→μν), 0.3% (W→eν)

- Lepton charge misidentification < 0.3% (electrons), ~ 10^{-4} (muons). The associated systematic uncertainty in the positive to negative cross section ratio $\propto$ (1.- charge ratio). Charge ratio~1 →effect is negligible.
- **Dominated by statistical uncertainties**