IL NUOVO CIMENTO Vol. 35 C, N. 3 Maggio-Giugno 2012
DOI 10.1393/ncc/i2012-11234-5

Colloquia: TOP2011

W-polarisation and constraints on Wtb-vertex

N. Castro on behalf of the ATLAS and CMS Collaborations
LIP, Departamento de Física, Universidade do Minho - 4710-057 Braga, Portugal

ricevuto l' 1 Marzo 2012
pubblicato online il 4 Giugno 2012

Summary. — The structure of the Wtb-vertex can be tested using single top and $t\bar{t}$ events collected at the LHC. The measurement of the t-channel single top quark production cross section by the CMS Collaboration was used to constrain the V_{tb} CKM matrix element, while the measurements of the helicity fractions of W bosons and angular asymmetries in top quark decays by the ATLAS Collaboration were used to constrain possible new physics contributions to the Wtb-vertex.

PACS 14.65.Ha – Top quarks.
PACS 12.38.Qk – Experimental tests.

1. – Introduction

The precise measurement of the top quark properties play an important role in testing the Standard Model and its possible extensions. At the LHC, events with top quarks can be originated via single top and $t\bar{t}$ production. The single top cross section measurement can be used as a test of the Cabibbo-Kobayashi-Maskawa (CKM) matrix structure. The W bosons in top decays can be produced with longitudinal, left-handed or right-handed polarisation. The fractions of events with a particular polarisation, F_0, F_{L} and F_{R}, respectively, are referred to as helicity fractions and are predicted in NNLO QCD calculations to be $F_0 = 0.687 \pm 0.005$, $F_{\mathrm{L}} = 0.311 \pm 0.005$, $F_{\mathrm{R}} = 0.0017 \pm 0.0001$ [1]. These fractions can be extracted from measurements of the angular distribution of the decay products of the top quark. The angle θ^* is defined as the angle between the momentum direction of the charged lepton from the decay of the W boson and the reversed momentum direction of the b-quark from the decay of the top quark, both boosted into the W boson rest frame. The differential decay rate is

$$(1) \qquad \frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta^*} = \frac{3}{8}\left(1+\cos\theta^*\right)^2 F_{\mathrm{R}} + \frac{3}{8}\left(1-\cos\theta^*\right)^2 F_{\mathrm{L}} + \frac{3}{4}\left(1-\cos^2\theta^*\right) F_0.$$

Information about the polarisation states of the W bosons can also be obtained by complementary observables, such as the angular asymmetries, A_+ and A_-, defined as

$A_{\pm} = \frac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)}$, with $z = \mp(2^{2/3} - 1)$ for $A_{\pm}$. The asymmetries can be related to the helicity fractions by a simple set of equations [2]. In the Standard Model, the NNLO values for these asymmetries are $A_+ = 0.537 \pm 0.004$ and $A_- = -0.841 \pm 0.006$. The measurements of the W-helicity fractions and the angular asymmetries in top quark decays by the ATLAS experiment at the LHC are described in the present paper. Such results can also be used to test the Wtb-vertex structure.

2. – Single top production and V_{tb} constraints

Using $36\,\mathrm{pb}^{-1}$ of pp collision data, the CMS collaboration measured the following t-channel single top quark production cross section [3]: $\sigma = 83.6 \pm 29.8(\mathrm{syst} + \mathrm{stat})$ pb. Assuming $|V_{tb}| = \sqrt{\frac{\sigma}{\sigma^{\mathrm{th}}}}$, where σ^{th} is the Standard Model theoretical prediction with $|V_{tb}| = 1$, this measurement can be used to constrain the V_{tb} CKM matrix element: $|V_{tb}| = 1.16 \pm 0.22(\mathrm{exp}) \pm 0.02(\mathrm{th})$. A lower bound at the 95% confidence level (CL) $|V_{tb}| > 0.62$ can also be inferred by assuming $0 \leq |V_{tb}|^2 \leq 1$.

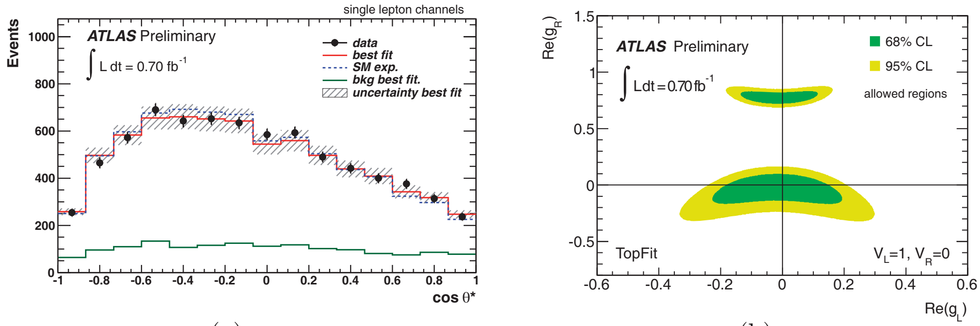
3. – W-polarisation measurements in $t\bar{t}$ events

Data from pp collisions collected with the ATLAS detector, and corresponding to an integrated luminosity of $0.70\,\mathrm{fb}^{-1}$, were used to measure the W-helicity fractions and angular asymmetries in top quark decays [4].

Two topologies for $t\bar{t}$ events were considered: 1) the single lepton channel, characterized by an isolated charged lepton (electron or muon) with large missing transverse energy corresponding to the neutrino from the leptonically decaying W boson, two light jets from the hadronically decaying W boson and two b quark jets; and 2) the dilepton channel, characterized by two isolated charged leptons with large p_{T}, missing transverse energy corresponding to the undetected neutrinos from the two leptonically decaying W bosons, and two b quark jets. The reconstruction of objects used in the analyses presented here followed the criteria developed for the measurement of the $t\bar{t}$ production cross section. The definition of objects, such as electrons, muons, jets and missing transverse energy as well as a description of the trigger requirements can be found in [5, 6].

3˙1. *Event reconstruction.* – Events in the single lepton channels were either reconstructed using a χ^2 minimisation technique or using a maximum likelihood estimate. Top quark pairs in the dilepton channels were reconstructed by solving a set of six independent equations, where the top and W masses are assumed to be 80.4 GeV and 172.5 GeV, respectively. The two jets with the largest p_{T} in the event were interpreted as b-jets. The pairing of the jets to the charged leptons was based on the minimisation of the sum of invariant masses $m_{\ell_1 j_1} + m_{\ell_2 j_2}$, where $\ell_{1,2}$ and $j_{1,2}$ are the possibilities for the two leptons and two jets with highest p_{T}, respectively. Up to four solutions can exist for the neutrino momenta. The solution with the minimum product of transverse neutrino momenta was chosen and is motivated by the low p_{T}-spectrum of neutrinos.

3˙2. *Measurement of the W-helicity fractions.* – Templates for different signal and background processes were fitted to the observed $\cos\theta^*$ distribution obtained from events reconstructed with the kinematic likelihood. In the single lepton channel, these were the three different helicity state signal processes, the QCD multijet background, the W+jets contribution and all other sources of background. In the dilepton channel, the templates were the three different helicity state signal processes and a single template representing



(a) (b)

Fig. 1. – (a) Distributions of $\cos\theta^*$ for data, fitted background, the Standard Model prediction and the best fit value for the combined single lepton channels. (b) Constraints on the Wtb-vertex anomalous couplings.

the different background contributions. A binned likelihood fit was used to estimate the number of expected events contributing to each template and assuming independent Poissonian fluctuations in each bin.

The helicity fractions measured combining the single electron and muon channels are: $F_0 = 0.57 \pm 0.07\,(\text{stat.}) \pm 0.09\,(\text{syst.})$, $F_{\rm L} = 0.35 \pm 0.04\,(\text{stat.}) \pm 0.04\,(\text{syst.})$ and $F_{\rm R} = 0.09 \pm 0.04\,(\text{stat.}) \pm 0.08\,(\text{syst.})$, as shown in fig. 1a. The dominant sources of systematic uncertainties are the signal modeling, the initial and final state radiation and the uncertainty on the b-quark tagging calibration.

The data sample analysed is not sufficient to allow a simultaneous fit of F_0 and $F_{\rm L}$ in the dilepton channels. A fit assuming $F_{\rm R} = 0$ can, however, be performed, yielding $F_0 = 0.75 \pm 0.08\,(\text{stat.} + \text{syst.})$ for the combination of single lepton and dilepton channels.

3˙3. *Measurement of the angular asymmetries.* – The angular asymmetries were measured using the $\cos\theta^*$ distribution obtained from events reconstructed with the χ^2 minimisation technique in the single lepton channels or with the method described above for the dileptonic channels. Correction factors were determined to correct for detector and reconstruction effects. An iterative procedure, after performing the subtration of the expected background, was used. The measured asymmetries using a combination of the single lepton and dilepton channels are: $A_+ = 0.54 \pm 0.02$ (stat.) $\pm\, 0.04$ (syst.) and $A_- = -0.85 \pm 0.01$ (stat.) $\pm\, 0.02$ (syst.). The total correlation coefficient between these measurements is 0.12. The systematic uncertainty dominates in the measurements of both asymmetries, with the dominant systematics being the signal modeling, the initial and final state radiation and the fake leptons background evaluation.

3˙4. *Constaints on the Wtb-vertex structure.* – Any deviations of the W-polarisation observables (W-helicity fractions and angular asymmetries) from the Standard Model prediction can be caused by new physics contributing to the Wtb-vertex. Such new interactions associated with the top quark may exist at higher energies and can be parametrised in terms of an effective Lagrangian [7-9]. The anomalous couplings, $V_{\rm R}$, $g_{\rm L}$ and $g_{\rm R}$, generated by dimension-six operators, are absent in the Standard Model at the tree level, while the Standard Model coupling $V_{\rm L} \equiv V_{tb}$ receives a correction from the operator $O_{\phi q}^{(3,3+3)}$.

Limits on anomalous couplings were obtained from the measured angular asymmetries by exploiting their dependence on these couplings, as implemented in the `TopFit` program [2]. The allowed regions on $(g_{\rm L}, g_{\rm R})$ are shown in fig. 1b, assuming $V_{\rm R} = 0$ and normalising to $V_{\rm L} = 1$. The upper disconnected region in the plot is due to a second large $g_{\rm R}$ solution in the quadratic equation relating the asymmetries to the anomalous couplings. However, this region would lead to single top production cross sections not compatible with the measured values. In addition to this two-dimensional limit it is useful to give limits on single anomalous couplings, taking only one of them non-zero at a time. These are, at 95% CL:

$$-0.34 < \mathrm{Re}(V_{\rm R}) < 0.39 \Rightarrow -11.2 < \frac{\mathrm{Re}\,(C^{33}_{\phi\phi})}{\Lambda^2} < 12.7\ \mathrm{TeV}^{-2},$$

$$-0.20 < \mathrm{Re}(g_{\rm L}) < 0.16 \Rightarrow -2.28 < \frac{\mathrm{Re}\,(C^{33}_{dW})}{\Lambda^2} < 1.90\ \mathrm{TeV}^{-2},$$

$$-0.19 < \mathrm{Re}(g_{\rm R}) < 0.13 \Rightarrow -2.27 < \frac{\mathrm{Re}\,(C^{33}_{uW})}{\Lambda^2} < 1.57\ \mathrm{TeV}^{-2},$$

where $C^{33}_{\phi\phi}$, C^{33}_{dW} and C^{33}_{uW} are the effective operators coefficients and Λ is the new physics scale. The W helicity fractions measured with the template method with F_R fixed to zero were used to obtain constraints on the C^{33}_{uW} coefficient, as proposed in [9]. The resulting central 95% probability interval on the coefficient of the operator, C^{33}_{uW}, was calculated using a Bayesian approach and found to be in agreement with zero: $-3.45 < \frac{\mathrm{Re}(C^{33}_{uW})}{\Lambda^2} < 1.80\,\mathrm{TeV}^{-2}$.

4. – Conclusions

The constraints on the V_{tb} CKM matrix element obtained from the measurement of the t-channel single top quark production by the CMS Collaboration were presented. The measurement of the W-polarisation observables by the ATLAS Collaboration was presented and the implications on the structure of the Wtb-vertex were discussed. A good agreement with the Standard Model expectations was found.

* * *

Nuno Castro is supported by Fundação para a Ciência e a Tecnologia, Portugal (project CERN/FP/116346/2010 and grant SFRH/BPD/63495/2009).

REFERENCES

[1] Czarnecki A. *et al.*, *Phys. Rev. D*, **81** (2010) 111503.
[2] Aguilar-Saavedra J. A. *et al.*, *Eur. Phys. J. C*, **50** (2007) 519.
[3] CMS Collaboration, *Phys. Rev. Lett.*, **107** (2011) 091802.
[4] ATLAS Collaboration, note ATLAS-CONF-2011-122 (2011) `https://cdsweb.cern.ch/record/1376422/files/ATLAS-CONF-2011-122.pdf`.
[5] ATLAS Collaboration, note ATLAS-CONF-2011-035 (2011) `https://cdsweb.cern.ch/record/1337785/files/ATLAS-CONF-2011-035.pdf`.
[6] ATLAS Collaboration, note ATLAS-CONF-2011-100 (2011) `https://cdsweb.cern.ch/record/1369215/files/ATLAS-CONF-2011-100.pdf`.
[7] Aguilar-Saavedra J. A., *Nucl. Phys. B*, **812** (2009) 181.
[8] Aguilar-Saavedra J. A., *Nucl. Phys. B*, **821** (2009) 215.
[9] Zhang C. *et al.*, *Phys. Rev. D*, **83** (2011) 034006.