PROCEEDINGS OF SCIENCE

Extraction of CKM matrix elements in the single-top t-channel events at 13 TeV with CMS

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The dominant electroweak production mechanism for single top quarks is the t-channel and it features a tWq vertex where q stands for b, s, or d quarks both in production and in the decay of the top quark. For this reason its cross section and branching fractions are sensitive to the strength of the electroweak coupling, making it a suitable channel for direct measurements of the magnitude of Cabibbo-Kobayashi-Maskawa (CKM) matrix elements $|V_{\rm tb}|$, $|V_{\rm ts}|$, and $|V_{\rm td}|$. A precise determination of the magnitude of these parameters of the standard model (SM) of particle physics allows to search for hints of potential contributions from new phenomena beyond the SM. This poster presents the first direct measurement of the CKM matrix elements $|V_{\rm tb}|$, $|V_{\rm ts}|$, and $|V_{\rm td}|$, making use of single top quark t-channel events in proton-proton collision data with a centre-of-mass energy of 13 TeV, collected with the CMS experiment at the LHC. The subset of data analysed corresponds to an integrated luminosity of 35.89 fb^{-1}.

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1. Single top quark production

Single top quarks are produced via the electroweak interaction through three main channels: t-channel, s-channel and tW associated production. The single top t-channel production process is particularly indicated to measure the Cabibbo-Kobayashi-Maskawa (CKM) elements $|V_{\rm tb}|^2$, $|V_{\rm ts}|^2$, and $|V_{\rm td}|^2$. The cross section and branching fraction can be written as:

$$\sigma_{t-\rm ch.,b}\mathcal{B}(\rm t \to Wb) + \sigma_{t-\rm ch.,b}\mathcal{B}(\rm t \to Wd,s) + \sigma_{t-\rm ch.,s,d}\mathcal{B}(\rm t \to Wb) + O(|V_{\rm td,s}|^4), \quad (1)$$

where $\sigma_{t-\rm ch.,q}$ stands for the production cross section happening via a q quark and it is proportional to $|V_{\rm tq}|^2$. $\mathcal{B}(\rm t \to Wq)$ stands for the decay branching fraction and can be written as $\mathcal{B}(\rm t \to Wq) = |V_{\rm tq}|^2\widetilde{\Gamma_{\rm q}}\Gamma_{\rm top}$, where $|V_{\rm tq}|^2\widetilde{\Gamma_{\rm q}}$ is the partial decay width and $\Gamma_{\rm top}$ is the total top quark decay width.

The final state of a single top quark t-channel event is characterized by the presence of a light jet (q′), usually at high values of pseudorapidity, missing transverse momentum coming from the neutrino (ν_ℓ) in the leptonic decay of the W boson, one isolated lepton (ℓ), a jet from the top quark (mostly a jet from b quark) and a jet coming from the gluon splitting, as can be seen by the Feynman diagrams reported in Figure 1.

2. Analysis strategy

The analysis [1] requires one isolated lepton (μ or e) and 2 or 3 jets, 1 or 2 of them are required to come from the hadronization of a b quark (b jet). This selection is designed to have high efficiency on the single top quark t-channel events, but it also accommodates for events coming from different processes like $t\bar{t}$, W + jets, multi-jet QCD and other single top quark production modes. The multi-jet QCD process has a huge cross section compared to all others processes and only few events pass the selection. For this reason the Monte Carlo simulation is not very reliable and to avoid big statistical fluctuations the shape of the kinematic distributions is extracted directly from data from an orthogonal phase space obtained by requiring a non-isolated lepton. Successively this background has been depleted by requiring the W boson transverse mass greater than 50 GeV.

Due to the presence of several irreducible backgrounds, three categories have been defined:

- 2-jets–1-tag rich in single top quark t-channel events with a $|\rm V_{tb}|^4$ term; the main backgrounds are W + jets and $t\bar{t}$ and a Boosted Decision Tree (BDT) has been trained against these two backgrounds.
- 3-jets–1-tag with the majority of the single top quark t-channel events with a $|V_{\rm tq}|^2$ term; the main backgrounds are W + jets and $t\bar{t}$ and a BDT has been trained to distinguish between single top quark t-channel events with a $|\rm V_{tb}|^4$ term, indicated as $ST_{\rm b,b}$, and single top quark t-channel events with a $|V_{\rm tq}|^2$ term, indicated as $ST_{\rm q,b} + ST_{\rm b,q}$.
- 3-jets–2-tags pure in single top quark t-channel events with a $|\rm V_{tb}|^4$ term; the main background is $t\bar{t}$ and a BDT has been trained against this background.

Then a simultaneous fit to the 6 regions (2 lepton flavour × 3 categories) is performed under different theoretical assumptions. Figure 2 shows the post fit distribution of the output of the BDT discriminator in the 3-jets–1-tag category.

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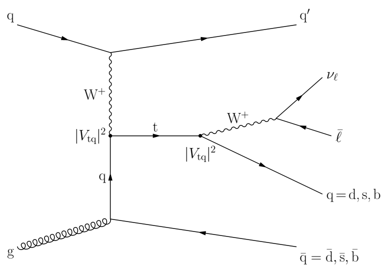

Figure 1: Feynman diagrams for single top quark t-channel events initiated by a b quark and decaying into a b or non-b quarks.[1]

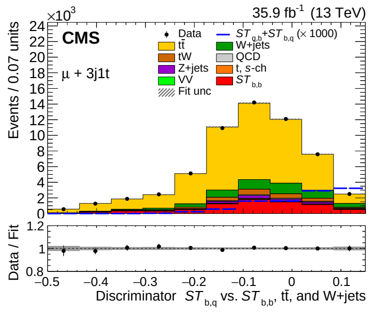

Figure 2: Post fit distribution of the output of the BDT discriminator in the 3-jets–1-tag category: the contribution in red is from $ST_{\rm b,b}$ events and the one represented by the dashed blue line is from $ST_{\rm q,b} + ST_{\rm b,q}$ events (scaled by 1000 to make it more visible).[1]

3. Results

The absolute values of CKM matrix elements are extracted from the fit results. Under the Standard Model (SM) assumption: $|V_{\rm tb}|^2 + |V_{\rm ts}|^2 + |V_{\rm td}|^2 = 1$, the results are:

$$|V_{\rm tb}|^2 > 0.970 \qquad |V_{\rm ts}|^2 + |V_{\rm td}|^2 < 0.057 \qquad \text{at 95\% confidence level,} \tag{2}$$

while allowing $|V_{\rm tb}|^2 + |V_{\rm ts}|^2 + |V_{\rm td}|^2 \neq 1$, the results are:

$$|V_{\rm tb}|^2 = 0.988 \pm 0.051 \qquad |V_{\rm ts}|^2 + |V_{\rm td}|^2 = 0.06 \pm 0.06 \tag{3}$$

Under the assumption in which Γ_t can vary to accommodate the non-SM decays, the results are:

$$|V_{\rm tb}|^2 = 0.988 \pm 0.024 \qquad |V_{\rm ts}|^2 + |V_{\rm td}|^2 = 0.06 \pm 0.06 \qquad \frac{\Gamma_{\rm t}^{\rm obs}}{\Gamma_t} = 0.99 \pm 0.42 \tag{4}$$

The results obtained show no deviation from the SM expectations and the value of $|V_{\rm tb}|^2$ is more precise than the last measurement performed by CMS at 13 TeV [2] and than the ATLAS and CMS combination at $\sqrt{s} = 7 - 8$ TeV [3].

References

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[3] M. Aaboud *et al.* [ATLAS and CMS], "Combinations of single-top-quark production cross-section measurements and $|f_{LV} V_{tb}|$ determinations at $\sqrt{s} = 7$ and 8 TeV with the ATLAS and CMS experiments," JHEP **05** (2019), 088 doi:10.1007/JHEP05(2019)088 [arXiv:1902.07158 [hep-ex]].