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$t\bar{t}H$ associated production in the all-jets final state with the CMS experiment

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Summary. — This work summarizes the state of the art of $t\bar{t}H$ searches performed by the CMS experiment in the all-jets final state, namely the final state in which the Higgs boson decays to a $b\bar{b}$ pair and both the top quarks decay hadronically. New possible analysis strategies are also investigated, exploiting final states in the so-called boosted topology when at least one of the partons has a high Lorentz boost and its decay products are reconstructed in the detector as a single, wide jet.

1. – State of the art of $t\bar{t}H$ searches in the all-jets final state

In the standard model (SM) framework, the Higgs boson is predicted to couple to fermions with a Yukawa-like interaction, the coupling being proportional to the fermion mass. Since the top quark is the most massive fermion, it has the greatest coupling to the Higgs boson. Indirect measurements of this coupling have been performed in loop-level processes (such as Higgs boson decay to photons); however, a direct measurement of the top-Higgs coupling exploiting tree-level processes, such as the $t\bar{t}H$ associated production, is crucial in order to exclude beyond-SM contributions which could enter the loops unnoticed. Among all the possible final states for the $t\bar{t}H$ associated production, the all-jets final state in which the Higgs boson decays to a $b\bar{b}$ pair and both the top quarks decay hadronically has the highest branching fraction ($\approx$25%). However, it turns out to be very challenging, having many particles that are difficult to identify (bottom quarks) and suffering from large contamination from the main background at hadron colliders, namely the QCD multijet production. The CMS Collaboration has performed a $t\bar{t}H$ analysis in the all-jets final state [1] and has quantified the result in terms of the so-called signal strength parameter μ, defined as the ratio of the observed cross section to the SM

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predicted cross section. In this work, the kinematic differences between the $t\bar{t}H$ production and the multijet production are exploited to discriminate signal from background through the matrix element method [2]. Specifically, events are assigned a probability density according to how compatible they are with signal and background processes. The measured value for the signal strength is found to be $\hat{\mu} = 0.9 \pm 0.7$ (stat) ± 1.3 (syst) and, since it is compatible with zero, an upper limit has been set as well resulting in $\mu < 3.8$ (3.1) at 95% CL.

2. – New possible analysis strategies: the boosted topology

Due to the high energy of the LHC collisions, the production of particles with high Lorentz boost whose decay products are very collimated and can be collected as single, wide jets, often referred to as boosted jets, is likely. The CMS detector [3] is able to collect information about the boosted jets substructure: important quantities are the number of subjets, their invariant masses, transverse momenta, b-tagging discriminators, flavors and angles.

A study has been performed about the applicaton of boosted techniques to $t\bar{t}H$ events in the all-jets final state. An optimal signal trigger has been chosen based on its efficiency on signal and QCD background; preselection cuts have been set in order to make this trigger fully efficient and enhance the signal-over-background ratio. Making strong use of multivariate techniques, it is possible to set up methods that exploit substructure variables and global event variables to discriminate signal events from the dominant background of the search, namely multijet production and $t\bar{t}$ production. Boosted decision trees (BDT) can be trained to identify boosted jets coming from Higgs bosons (Higgs candidates, HCs) and top quarks (top candidates, TCs); if no HCs are found, an additional BDT can be set up to identify $t\bar{t}H$ events in which the Higgs boson decays to a pair of well resolved, b-tagged jets. The discriminator resulting from this last multivariate method is shown in fig. 1. Based on the Higgs boson decay topology, on the number of TCs and on the number of jets, $t\bar{t}H$ events can be split into 9 boosted

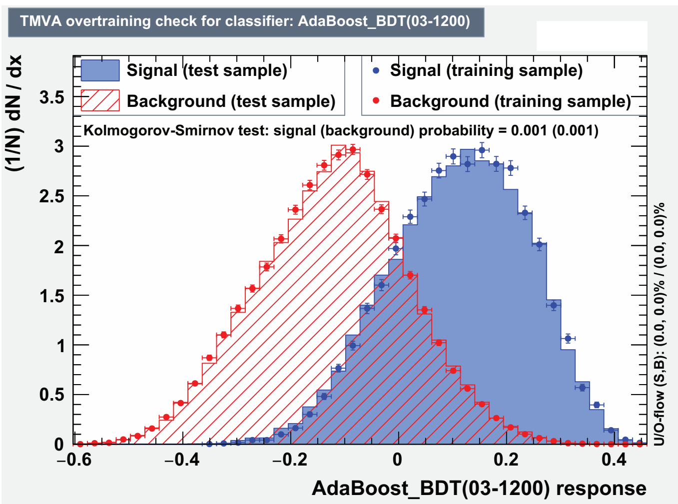

Fig. 1. – Distribution of the BDT discriminator used to identify $t\bar{t}H$ events containing a resolved Higgs. A good discriminating power between signal and background events is obtained.

TABLE I. – *Expected yields corresponding to the integrated luminosity of the 2016 data taking period (35.9 fb^{-1}). Signal ($t\bar{t}H$) and dominant background (QCD and $t\bar{t}$) yields are reported, as well as the significance of each category computed as signal over the square root of background. Boosted Higgs categories run from C0 to C8, while the remaining ones are resolved Higgs categories.*

Cat.	$t\bar{t}H$ (S)	QCD (B_1)	$t\bar{t}$ (B_2)	$S/\sqrt{B_1 + B_2}$
C0	4.0	366	153	0.18
C1	15.4	16565	910	0.12
C2	5.7	330	107	0.27
C3	7.2	1693	621	0.15
C4	28	14216	1632	0.22
C5	25	96466	3620	0.07
C6	6.0	1062	165	0.17
C7	7.1	5526	695	0.09
C8	3.7	19615	718	0.10
C9	8.9	792	332	0.27
C10	24.2	5608	1348	0.29
C11	4.8	460	247	0.18
C12	8.7	1884	414	0.18

Higgs categories and 4 resolved Higgs categories, resulting in the expected yields and significances reported in table I.

3. – Conclusions

$t\bar{t}H$ events in the all-jets decay channel offer a unique possibility to study the top-Higgs Yukawa coupling in a fully reconstructed final state. The boosted approach, based on the presence of wide jets, is complementary to the ongoing CMS analyses and can be used to compute an upper limit on the signal strength parameter μ, possibly exploiting the full Run 2 dataset (2016 + 2017 + 2018 data taking periods). A combination between resolved and boosted analyses may also be feasible.

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