Higgs Boson Reaching the Top

A new way to produce a Higgs boson, the elementary particle discovered in 2012, has been observed for the first time at the CMS experiment at the CERN LHC. Here, the Higgs boson is produced together with two top quarks, the heaviest known elementary particles. Physicists at KIT in the group of Prof. Husemann had major contributions to this result.

The Higgs boson, which has been discovered in 2012 at the LHC, has a unique role in the standard model of particle physics, which describes the known elementary particles and their fundamental interactions. The Higgs boson is closely related to the mechanism that generates the masses of the particles, and a precise understanding of its properties is one of the major goals of the LHC physics programme. In particular, the measurement of the Higgs boson's interaction with the heaviest known particle, the top quark, is of paramount interest. According to the standard model, this interaction is very large, and a measurement of its strength constitutes a crucial validation of the model. The measurement can best be performed in extremely rare proton-proton collision events in which a Higgs boson is produced together with a top quark-antiquark pair ($t\bar{t}H$ production).

After their production, both the Higgs boson and the top quarks decay almost instantly into further elementary particles, which can again decay further, generating complicated signals in the particle detectors. Project coordinator Matthias Schröder at KIT: "Identifying these extremely rare processes against the background of processes that look very similar in the detector but occur almost 1500 times more often is a major challenge, which could only be solved after several years of data analysis." The foundation for this measurement was already laid 20 years ago in Karlsruhe in the context of a diploma thesis supervised by Prof. Müller – but only after years of LHC operation, enough data has been collected to perform the measurement. The KIT group, in close collaboration with DESY in Hamburg and the RWTH Aachen, had a leading role in the analysis of events with bottom quarks, which contribute particularly strong to the result.

Combining the data collected since 2011 in approximately 4 million billion proton-proton collisions at centre-of-mass energies of 7, 8 and 13 teraelectronvolts, $t\bar{t}H$ production has now been observed for the first time at the CMS experiment. A candidate of a single $t\bar{t}H$ signal event is shown in Fig. 1. A small excess of events above the overwhelming background has been observed, which is compatible with the expectations for $t\bar{t}H$ production and which is clear enough that a purely statistical fluctuation can be excluded with high probability. The significance of the excess corresponds to 5.2 standard deviations, the corresponding test statistic is depicted in Fig. 2.

The observation of $t\bar{t}H$ production establishes a further production mechanism of the Higgs boson and verifies its direct interaction with the top quark. This marks an important milestone in understanding the Higgs boson and confirms the theoretical predictions of the standard model. The results have been published by the CMS collaboration in the journal Physical Review Letters, and they have been confirmed recently by the ATLAS experiment.

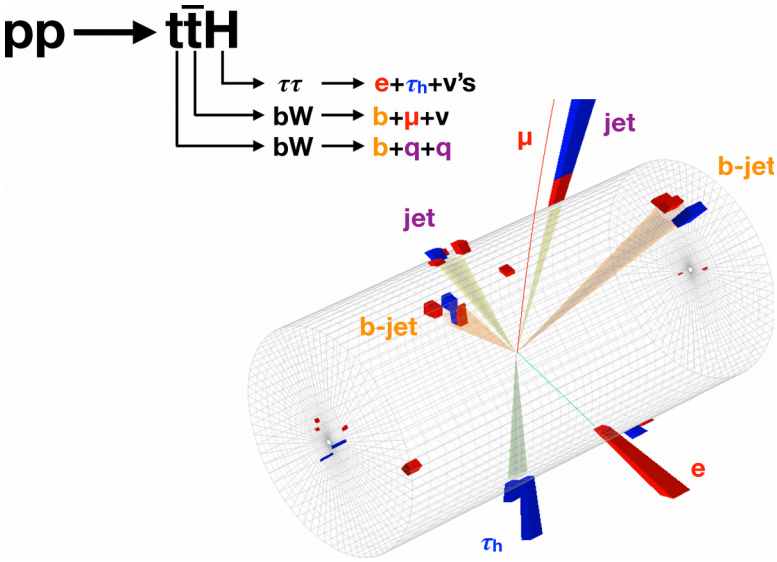

Fig. 1 Visualisation of the detector signals of a ttH candidate event.

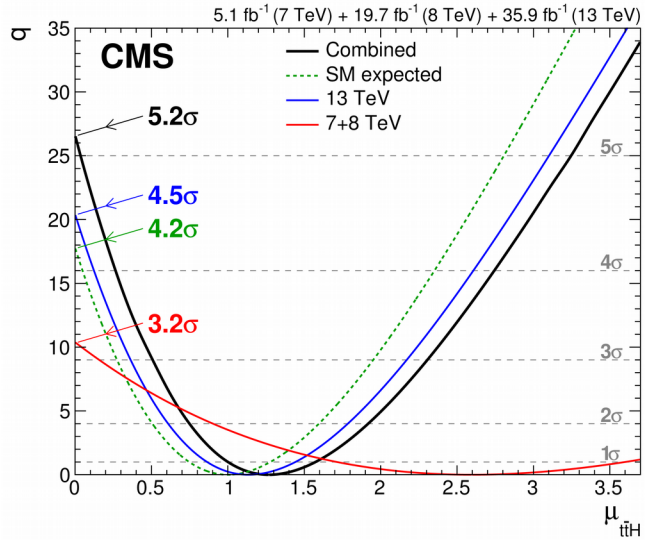

Fig. 2 Test statistic q as a function of the measured ttH signal strength relative to the standard model expectation, for the analysis of the data at 7 and 8 TeV, 13 TeV, and their combination.