Measurement of the Higgs boson production in association with top quarks in final states with multileptons using data taken during the Run 2 of the LHC with CMS

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Introduction:

Measurement of a top quark pair production in association with a Higgs boson in **final states with multiple leptons** (e,μ,τ)

- Data taken by the CMS experiment at LHC at 13 TeV during Run 2 (2016, 2017 and 2018).
- ttH and tH processes provide the **most precise** model-independent determination of the **Yukawa coupling of the Higgs to the top quark** (yt).
- The analysis yields 5σ sensitivity for ttH.

Event Selection:

- Small signal compared to other SM processes
- Selected final states target the Higgs boson decays: H→WW, H→ZZ and H→ττ.

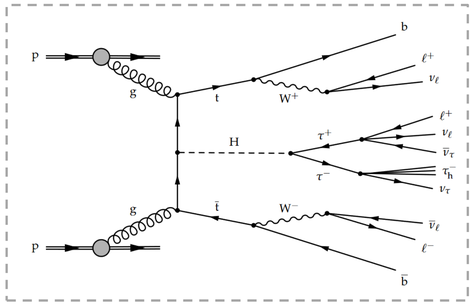
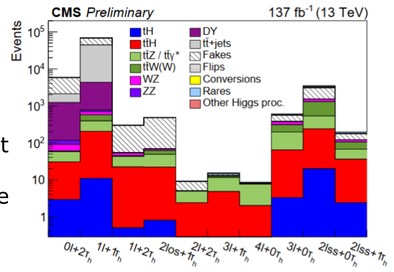


Fig: Example of Feynman diagram for ttH production. Subsequent decay of the H to ττ, producing a final state with two same-sign leptons and one reconstructed tau.

- **10 categories** are defined depending on the number of leptons and hadronic τ in the final state
- **Selection:**
  - Jet multiplicity requirement according to the number of jets in the final state
  - B jet requirement
  - Z veto and $m_{\ell\ell}$ requirements in some categories



- **Lepton ID** is based on a **BDT discriminant** to reject non-prompt leptons

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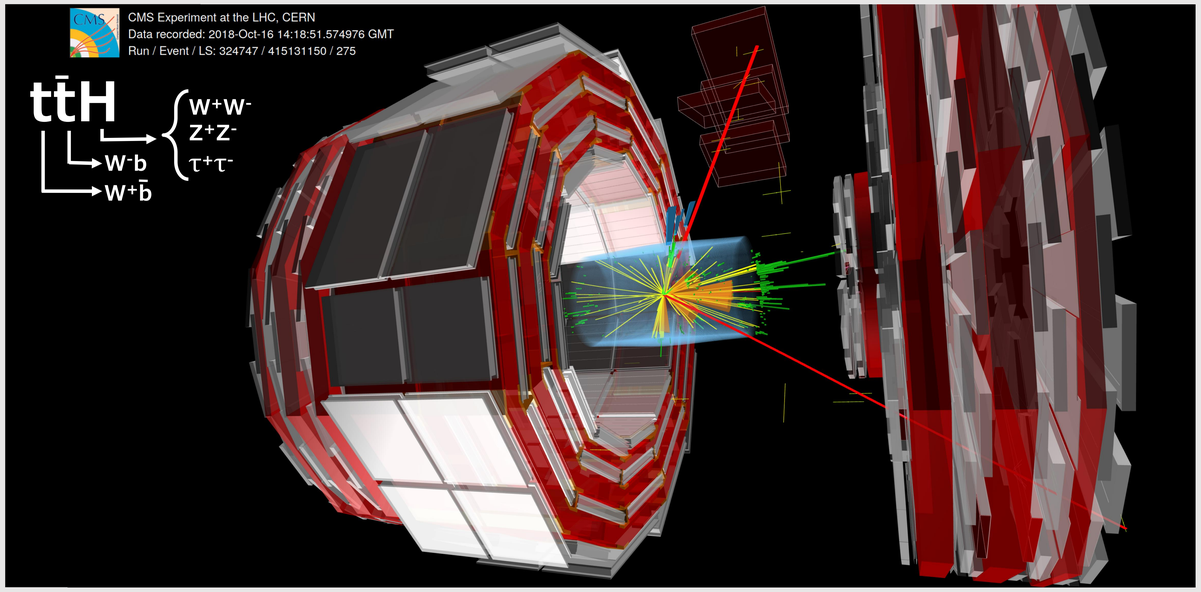

Results and conclusions:

- Measured **signal strength** for ttH and tH in good agreement with the Standard Model:
- Significance:

$$\mu_{ttH} = 0.92^{+0.26}_{-0.23} \qquad \mu_{tH} = 5.67^{+4.1}_{-4.0}$$

  ttH: 5σ (4.7σ) expected (oberved)
  tH: 1.4σ (0.3σ) expected (oberved)
- y_t **constrained** to be within **$-0.9 < y_t < -0.7$** and **$0.7 < y_t < 1.1$** at 95% CL

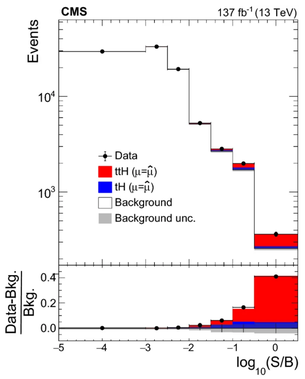

Fig: Decimal logarithm of the ratio between expected signal and expected background in each bin of the distribution used for signal extraction

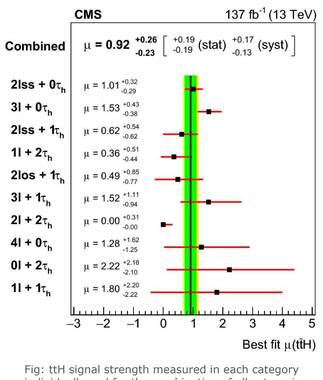

Fig: ttH signal strength measured in each category individually and for the combination of all categories.

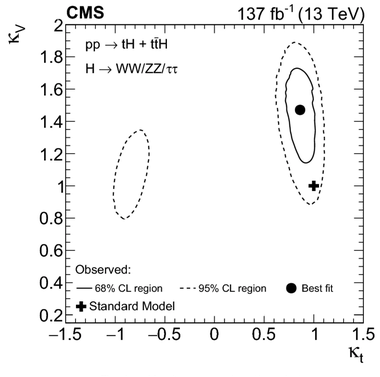

Fig: Log Likelihood as a function of kt and kv.

References:

The CMS Collaboration, *Higgs boson production in association with top quarks in final states with electrons, muons, and hadronically decaying tau leptons at √s=13 TeV*. **Eur. Phys. J. C 81 (2021) 4, 378**

Background discrimination:

- **Main backgrounds:**

⇒ ttZ and ttW production: estimated with MC simulation

⇒ Mis-identified leptons: estimated with data-driven methods. Using **loose-to-tight** methods and deriving factors in data driven control regions.

- **MVA techniques** are used **to discriminate** signal from background:
  - multiclass NNs used in categories with high stats. and sensitive to ttH and tH (2ℓss + $1\tau_h$, 2ℓss+ $0\tau_h$ and 3ℓ +0 τ_h)
  - BDTs on categories with lower stats: separate ttH+tH against the backgrounds.
  - Inputs: 3-momenta (of leptons, τ_h and jets), angular variables, masses, object multiplicity…

For 2ℓss+ $0\tau_h$ DNN output (4 nodes):

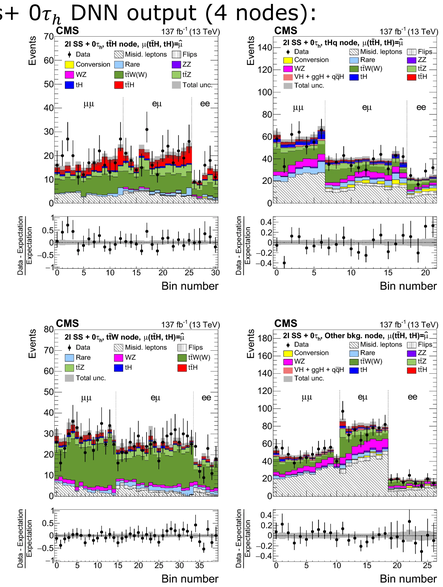

Fig: Distributions in the discriminating observables used for the signal extraction in the 2lss + $0\tau_h$ category. Each plot shows one of the DNN output nodes targeting ttH, tHq, ttW and other processes.

Signal Extraction:

- A Maximum likelihood fit is performed to extract the signal strength. All categories and two control regions for ttW and ttZ are used.
- **Interpretation** in terms of **Yukawa coupling** modifier (κ framework):
  - Scan in κt κv points
  - Considering: cross section and shape modifications, interference of diagrams with t-H and t-W coupling for tHq and tHW and Higgs BR modifications