Measurements of Higgs boson production in decay channel with a tau lepton pair

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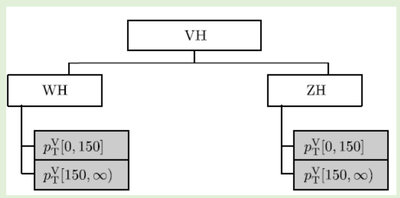
VH analysis

Final states considered are based on the vector boson decay mode
- **1 lepton ($W \to e\nu, W \to \mu\nu$)**
- **2 leptons ($Z \to ee, ZZ \to \mu\mu$)**

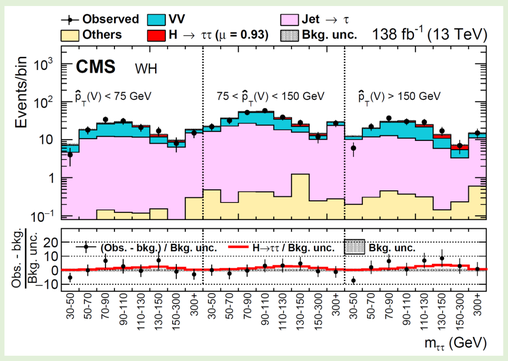
and three final states of the Higgs boson decay into a tau lepton pair: $e\tau_h, \mu\tau_h, \tau_h\tau_h$

Dominant background: $W(\ell\nu)Z(\tau\tau)$ for WH and $ZZ \to 4\ell$ for ZH
- Background with jets misidentified as τ_h: Estimated in $Z \to \mu\mu + \tau_h$ events with two hadronic tau lepton isolation regions
- Background with jets misidentified as e: Estimated in $Z \to \mu\mu +$ e events with two electron isolation regions
- Background with jets misidentified as μ: Estimated in $Z \to ee + \mu$ events with two muon isolation regions

4 STXS bins are considered:



Result extracted from 2D distributions with $m_{\tau\tau}$ and p_T of reconstructed vector boson

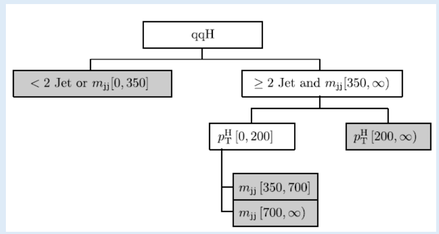


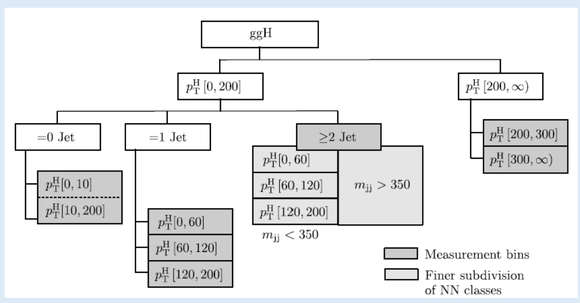
qqH, ggH analysis

Four final states are considered: $e\mu, e\tau_h, \mu\tau_h, \tau_h\tau_h$

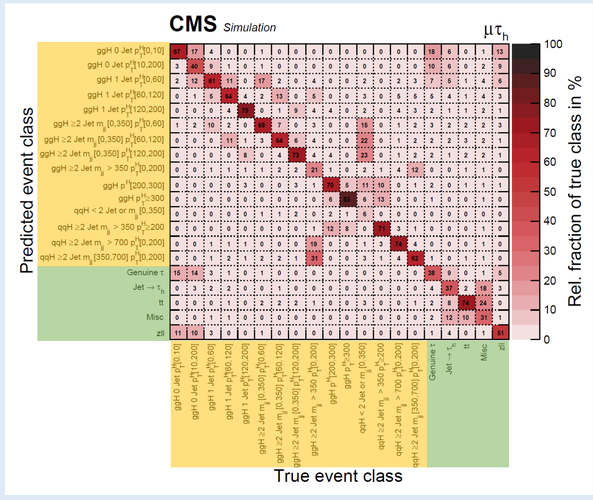
Dominant backgrounds: **Z+jets, W+jets, $t\bar{t}$, QCD multijet**
- Background with two genuine tau leptons: **Tau embedding method**
- Background with jets misidentified as τ_h: **Fake factor method**
- Background with jets misidentified as e or μ: **OS/SS method**
- All other backgrounds are estimated from simulation

12 STXS bins are considered:





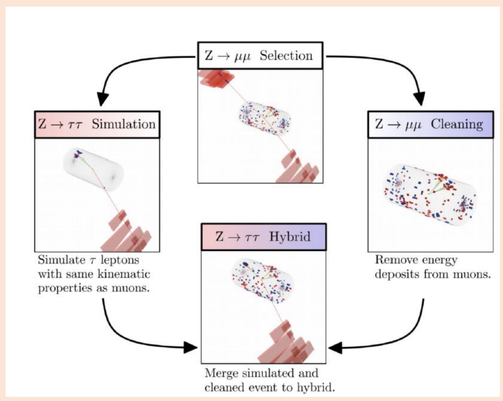
Event categorization is based on neural network multi classification with **15 signal classes** and **5 background processes**



Tau embedding method

Estimation of all backgrounds with two real τ (mostly from Z boson decay)

- $\mu\mu$ events selected in data
- Energy deposits of muons removed, replaced by simulated tau leptons with the same kinematics

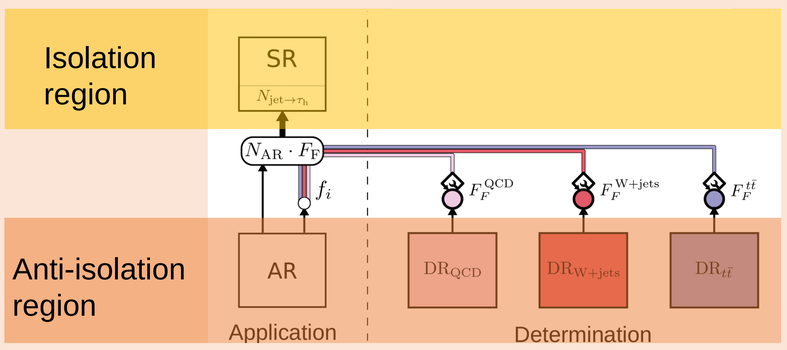


Fake factor method

Estimation of background with jets initiated by quarks or gluons and misidentified as hadronically decaying tau leptons (especially $\tau_h\tau_h$ channel has large contribution)

- Anti-isolation region: Tau lepton isolation vs jets is reverted
- 3 determination regions for QCD multijet, W+Jets and $t\bar{t}$ (for $\tau_h\tau_h$ channel only QCD)
- Fake factors weighted with fraction of background contribution in AR:

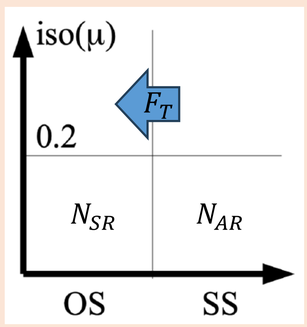
$$F_F = f_{\mathrm{W+jets}} \cdot F_F^{\mathrm{W+jets}} + f_{\mathrm{QCD}} \cdot F_F^{\mathrm{QCD}} + f_{\mathrm{t\bar{t}}} \cdot F_F^{\mathrm{t\bar{t}}}$$



OS/SS method

Estimate background with jets misidentified as electrons or muons in $e\mu$ channel
- Application region defined with same sign of q_e and q_μ
- Determination region with anti-isolated muons and isolated electrons give transfer factor F_T from AR to SR
- Extrapolate the number of fake leptons to the signal region with:

$$N_{SR} = F_T N_{AR}$$



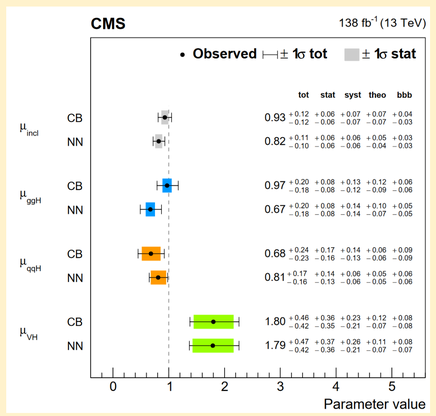
Results

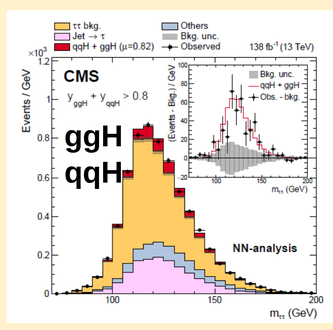
Inclusive signal strength:
$$\mu_{\mathrm{incl}} = 0.82^{+0.11}_{-0.10},$$
compatible with SM exp. within 2σ

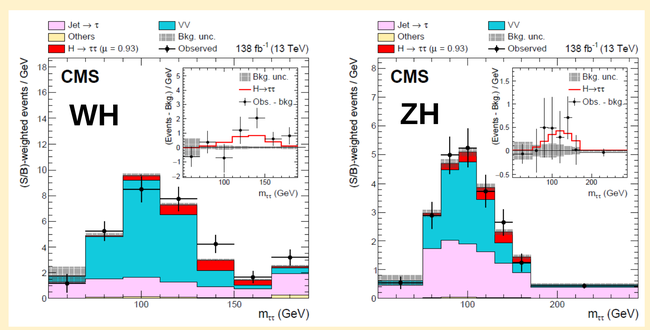
ggH signal strength:
$$\mu_{ggH} = 0.67^{+0.20}_{-0.18}$$

qqH signal strength:
$$\mu_{qqH} = 0.81^{+0.17}_{-0.16}$$

VH signal strength:
$$\mu_{VH} = 1.79^{+0.47}_{-0.42}$$







STXS measurement performed in a total of 16 STXS bins

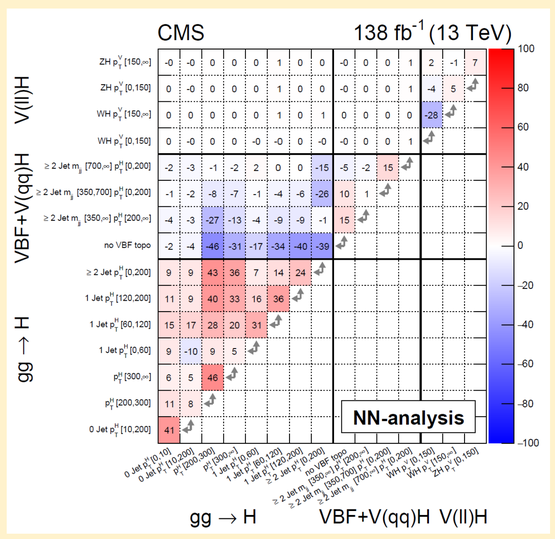
Anticorrelation observed between ggH ≥ 2 jets and qqH processes

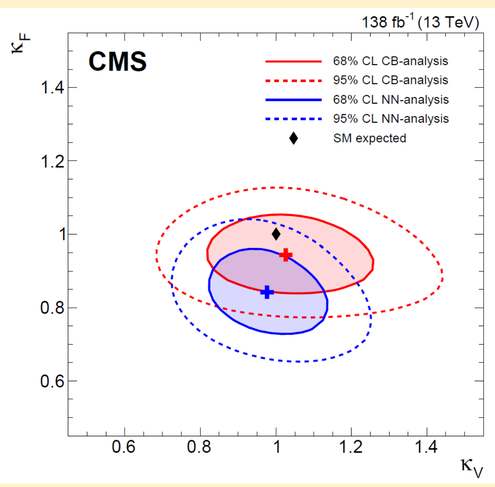
No correlation between VH and ggH/qqH

Higgs coupling to fermions (κ_F) and vector bosons (κ_V)

$H \to WW$ treated as signal

κ_V close to one, κ_F 15% lower than SM expection





Reference

CMS Collaboration, «Measurements of Higgs boson production in the decay channel with a pair of τ leptons in proton-proton collisions at $\sqrt{s}$=13 TeV", EPJC 83 (2023) 562

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