Karlsruher Institut für Technologie

Institute of Experimental Particle Physics

Higgs boson differential and STXS measurements in the fermionic channels

07.07.2022
ICHEP, Bologna

Sebastian Brommer for the CMS collaboration

Institut für Experimentelle Teilchenphysik (ETP), Fakultät für Physik

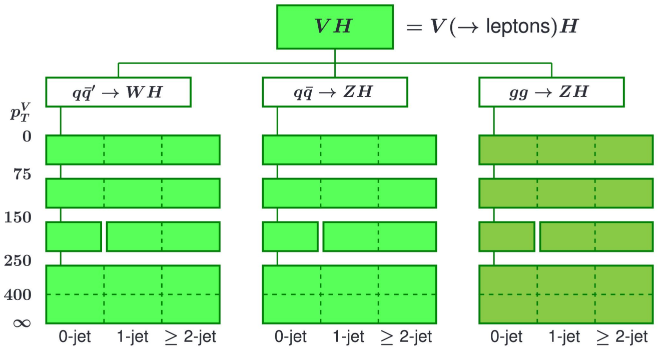
Fermionic differential & STXS measurements by CMS

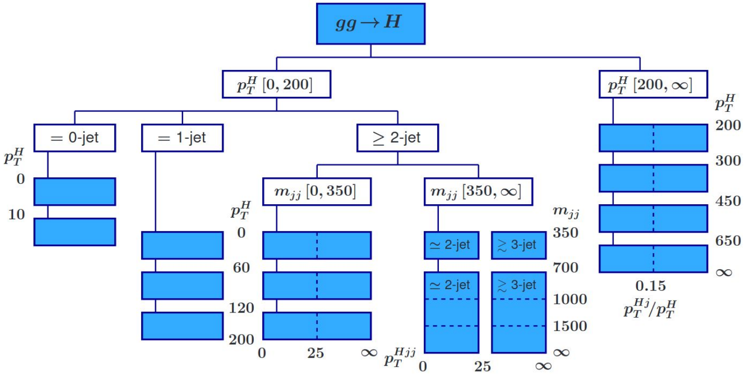
1. H →bb (boosted ggH)

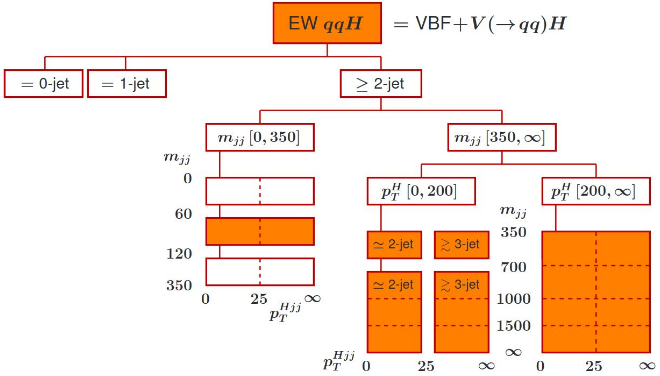
   JHEP12(2020)085
2. H → ττ (differential)

   10.1103/PhysRevLett.128.081805
3. H → ττ (ggh, VBF, VH)

   2204.12957







Fermionic differential & STXS measurements by CMS

1. H →bb (boosted ggH)

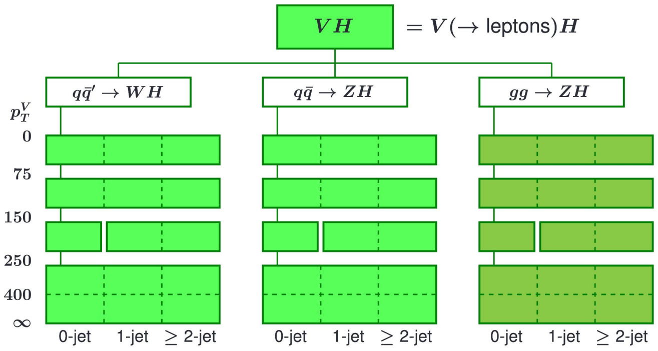
   JHEP12(2020)085

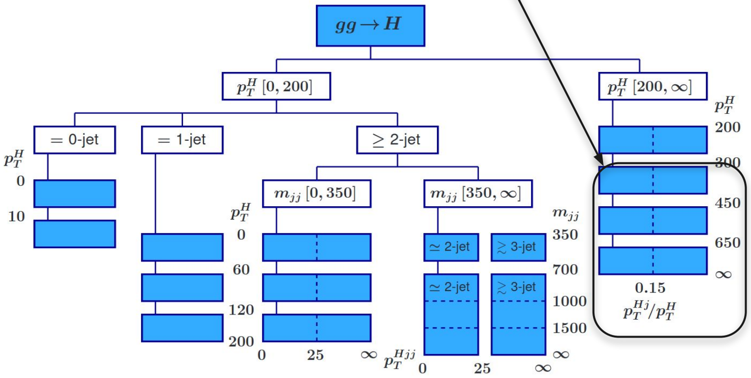
2. H → ττ (differential)

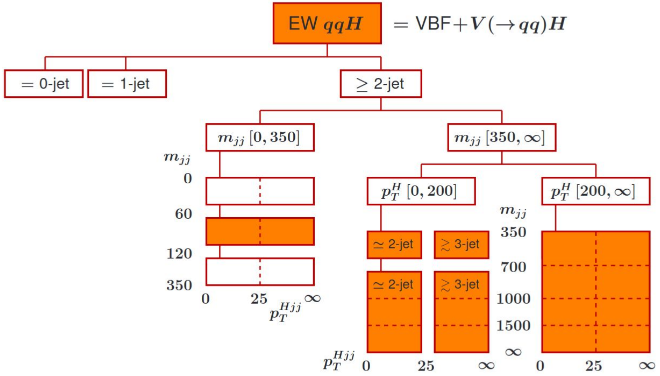
   10.1103/PhysRevLett.128.081805

3. H → ττ (ggh, VBF, VH)

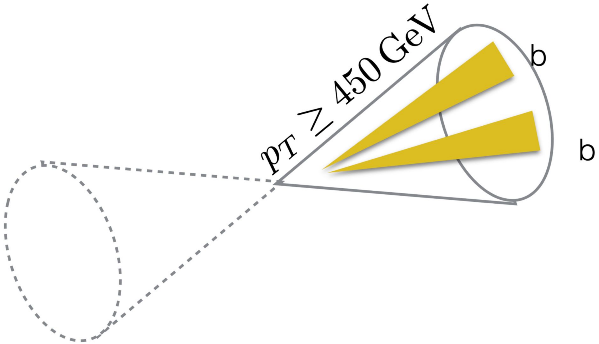
   [2204.12957](2204.12957)







H → bb (boosted ggH)



Selection of highly boosted events with jet p_T > 450 GeV into 6 categories based on the jet momentum

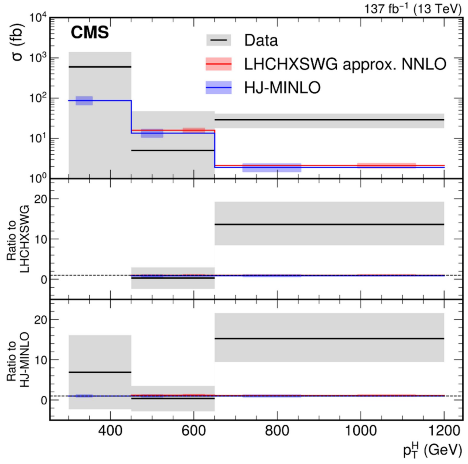
Discriminant: Jet mass after the application of soft drop (M_{SD})

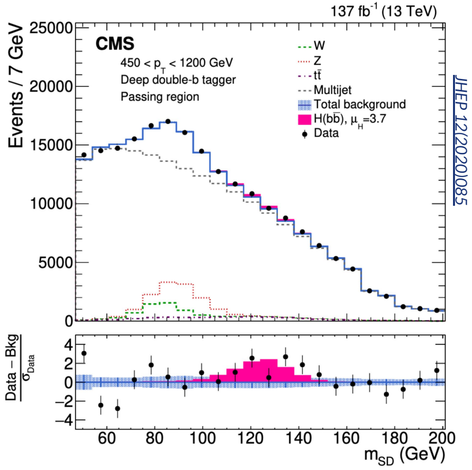
10.1007/JHEP05(2014)146

$$\mu_{incl} = \boxed{3.7 \pm 1.2\,(\text{stat})^{+0.8}_{-0.7}\,(\text{syst})^{+0.8}_{-0.5}\,(\text{theo})}$$

Additional measurement based on STXS binning

In total: 3 ggH STXS bins measured





JHEP 12(2020)085

Fermionic differential & STXS measurements by CMS

1. H →bb (boosted ggH)

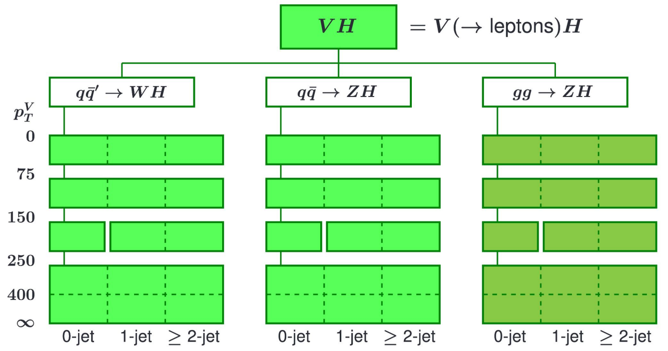
   JHEP12(2020)085

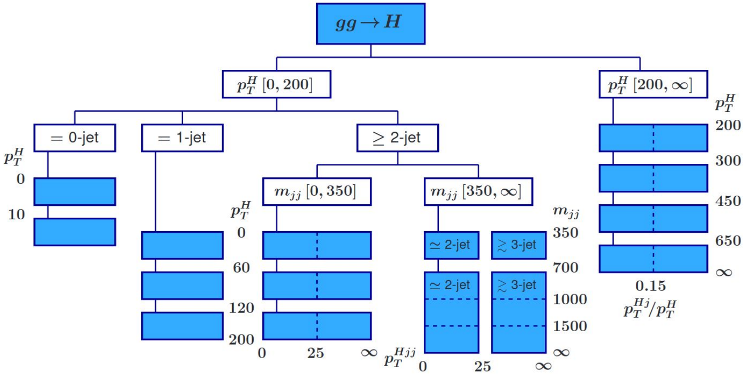
2. H → ττ (differential)

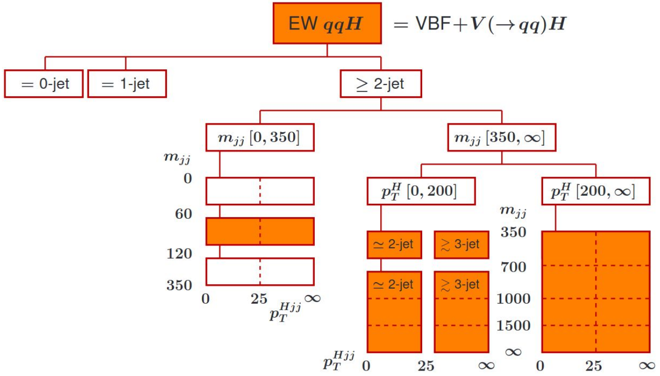
   10.1103/PhysRevLett.128.081805

3. H → ττ (ggh, VBF, VH)

   2204.12957







H → ττ Background Estimation

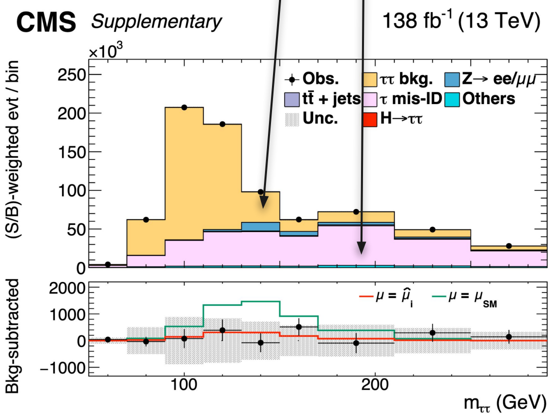
Majority of backgrounds are estimated from data

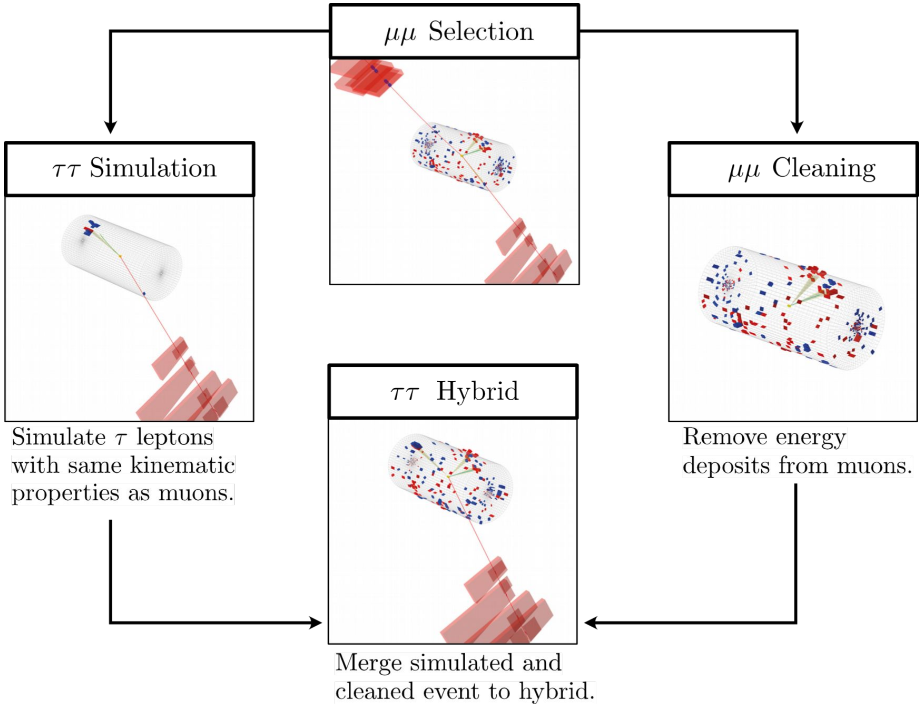
Genuine ττ events : estimated using Tau Embedding

(10.1088/1748-0221/14/06/P06032)

Jets misidentified as τ_h: estimated using F_F method

(JHEP09(2018)007)





H → ττ Differential Cross Section Measurement

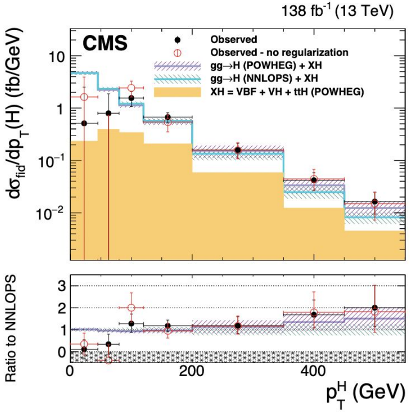
Differential measurement using four di-τ pair final states

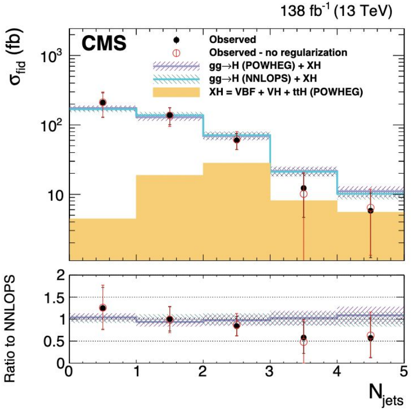
$e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$

The differential cross sections measured as a functions of

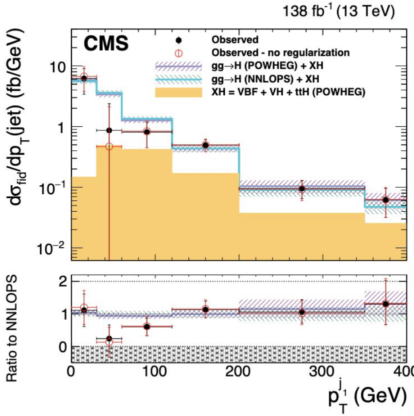
1. Higgs boson transverse momentum,
2. the jet multiplicity
3. transverse momentum of the leading jet

First differential measurement of H→ττ





10.1103/PhysRevLett.128.081805



Fermionic differential & STXS measurements by CMS

1. H →bb (boosted ggH)

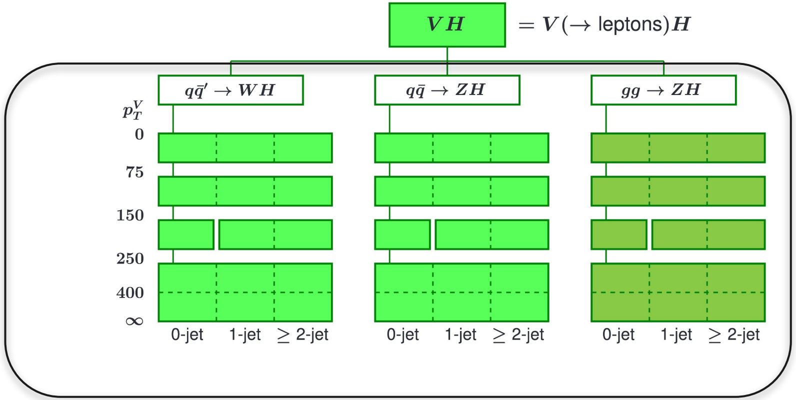
   [JHEP12(2020)085]

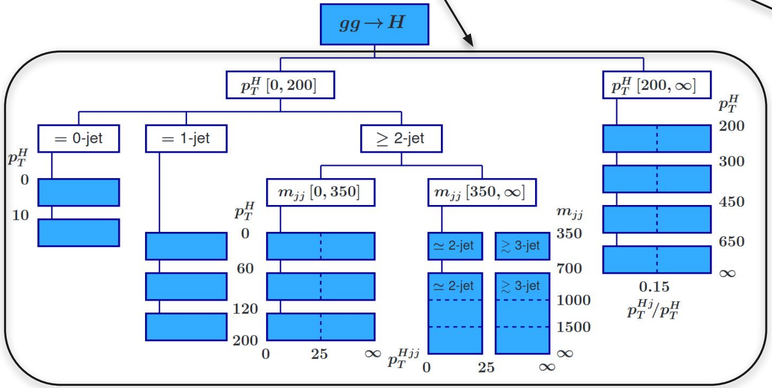
2. H → ττ (differential)

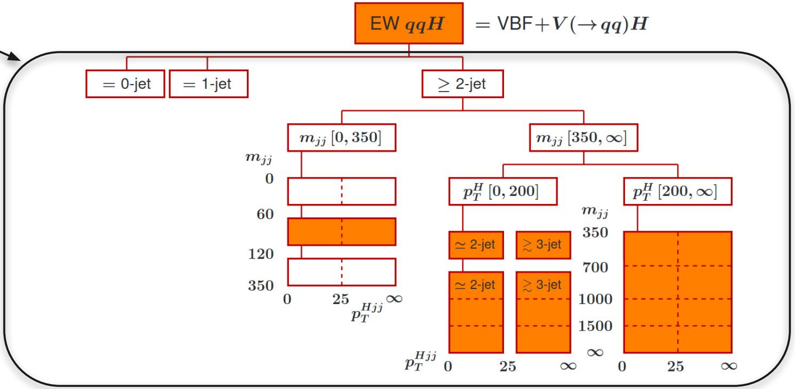
   [10.1103/PhysRevLett.128.081805]

3. H → ττ (ggh, VBF, VH)

   [2204.12957]







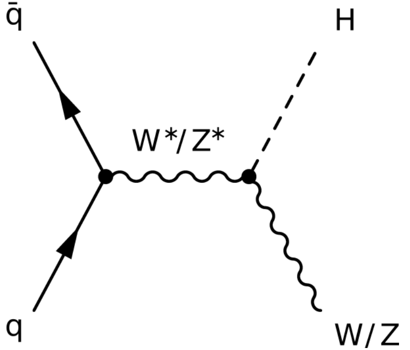
$H \rightarrow \tau\tau$ (VH) Measurement Overview

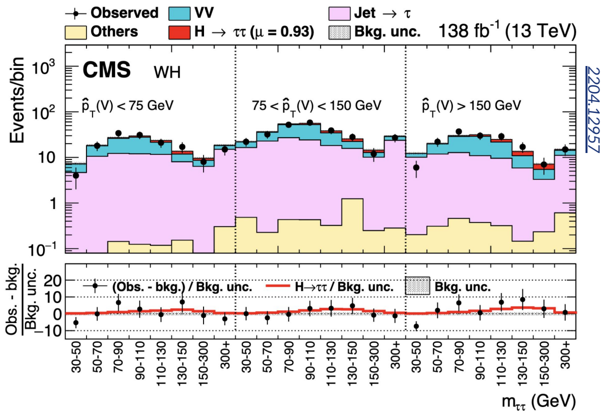
Categorization based on the **vector boson decay mode**

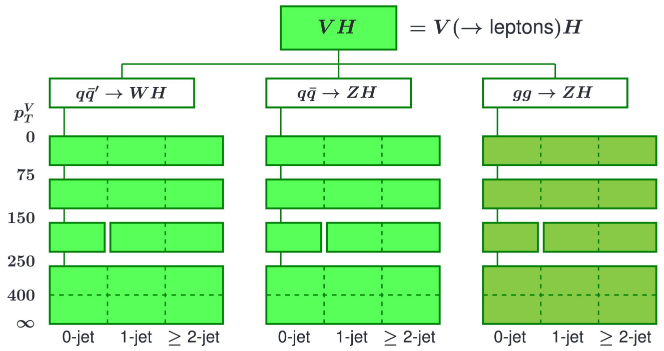
- 1 lepton (W→eν, W→μν)
- 2 lepton (Z→ee, Z→ μμ)

+ p_T of the vector boson

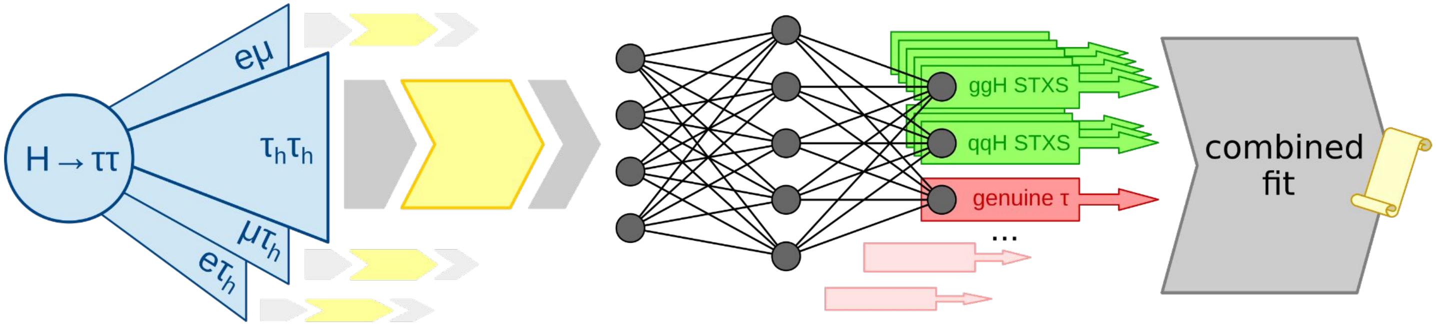
2D distributions using $m_{\tau\tau}$ and p_T of the vector boson







$H \rightarrow \tau\tau$ (ggH,qqH) Measurement Overview



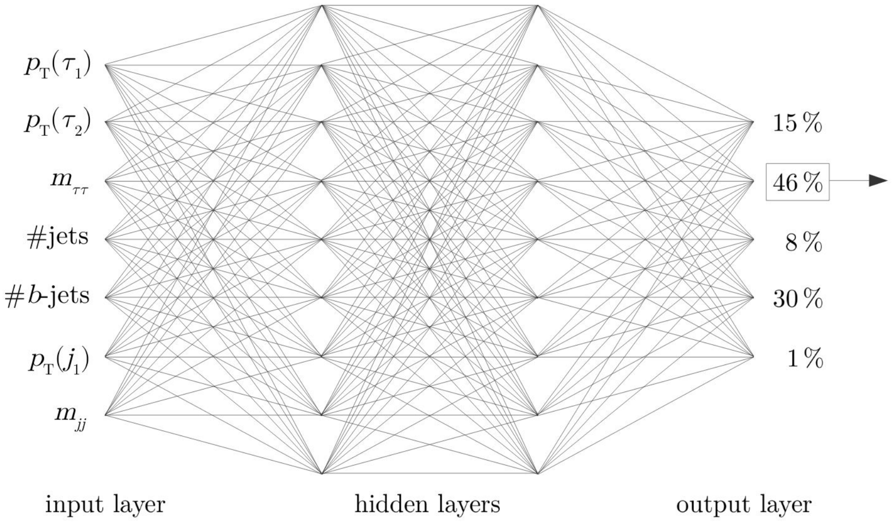
Four di-τ pair final states
eμ, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$

Event categorization is based on neural network (NN) multi-classification

Measurement of **inclusive** and **STXS stage** signals

$H \rightarrow \tau\tau$ (ggH,qqH) Neural Network for Classification

Simple NNs with 2 hidden layers is **sufficient** for this classification task

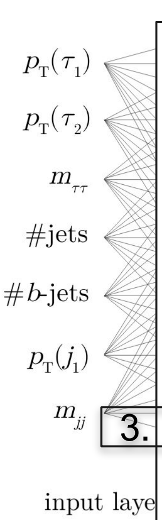


H → ττ (ggH,qqH) Neural Network for Classification

Simple NN with 2 hidden layers is **sufficient** for this classification task

15 input variables used, most important

$m_{\tau\tau}$, m_{vis}, m_{jj} (+ *correlations*)

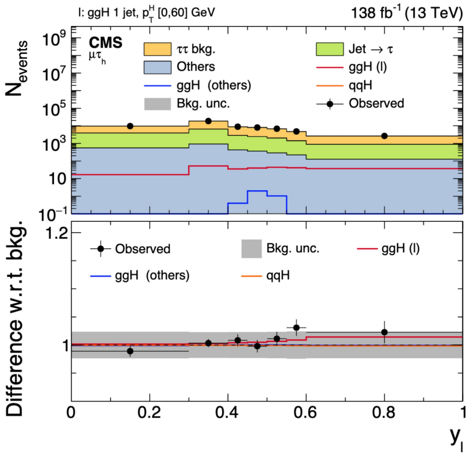


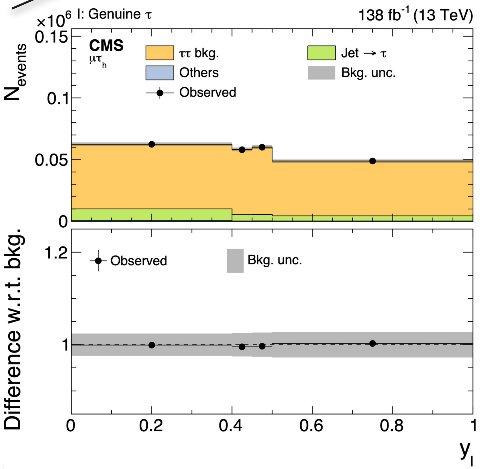
Variable	$\mu\tau_h$	$e\tau_h$	$\tau_h\tau_h$	$e\mu$
p_T^{e,μ,τ_h}	✓	✓	✓	✓
p_T^{e,μ,τ_h}	✓	✓	✓	✓
$m_T^{e,\mu}$	—	—	—	✓
$p_T^{1.\ Jet}$	✓	✓	✓	✓
$p_T^{2.\ Jet}$	✓	✓	✓	✓
N_{Jets}	✓	✓	✓	✓
$N_{b\text{-}Tag}$	✓	✓	✓	—
3. m_{jj}	✓	✓	✓	✓
$\Delta\eta_{jj}$	✓	✓	✓	✓
p_T^{jj}	✓	✓	✓	✓
1. $m_{\tau\tau}$	✓	✓	✓	✓
2. m_{vis}	✓	✓	✓	✓
p_T^{vis}	✓	✓	✓	✓
MELA output	✓	✓	✓	✓
Era	✓	✓	✓	✓

H → ττ (ggH,qqH) Neural Network for Classification

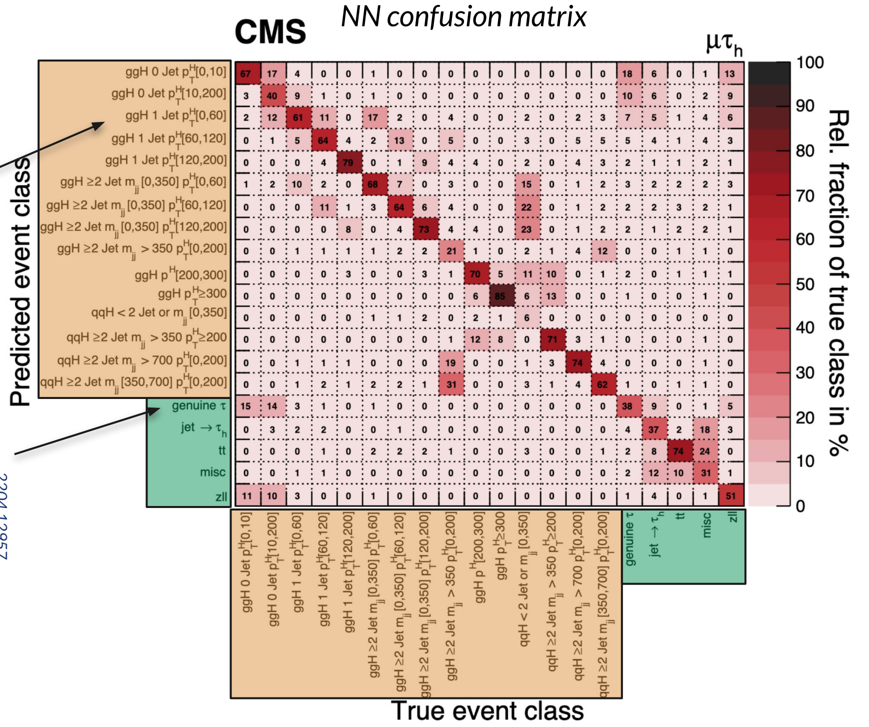
15 nodes for the signal classes congruent with the **STXS binning**

3 (5) nodes for different background processes, depending on the final state





2204.12957

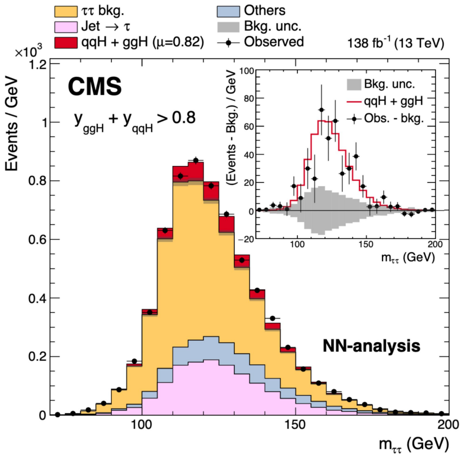


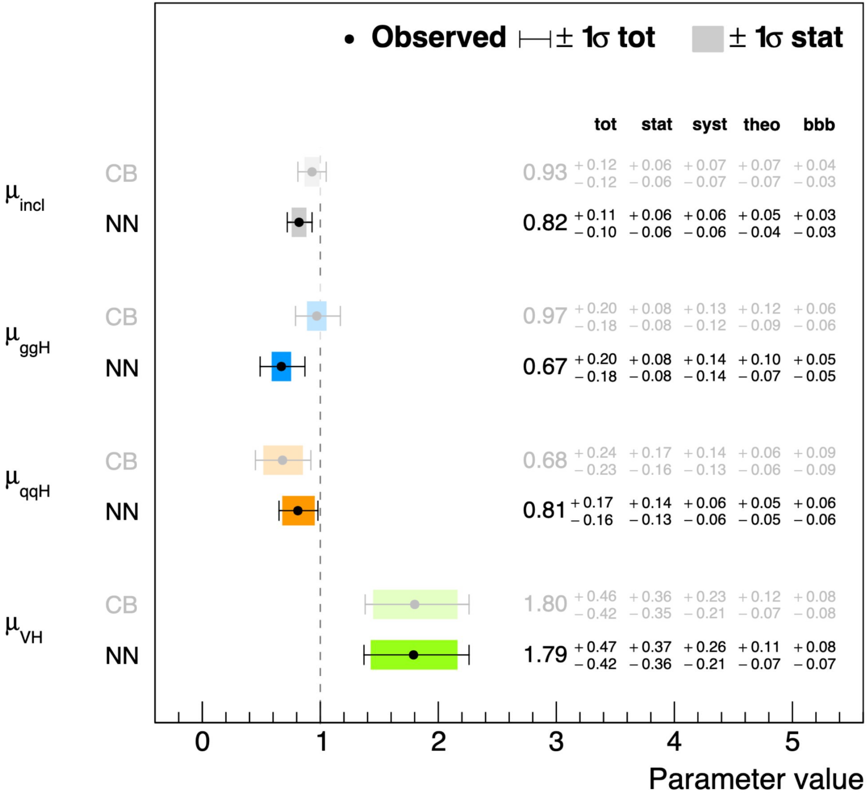
$H \to \tau\tau$ Inclusive Results

μ_{incl} = 0.82 (+0.11 - 0.10)

p-value for compatibility of incl. with SM: **0.10**

Correlation between μ_{ggH} and μ_{qqH}: **-0.35**





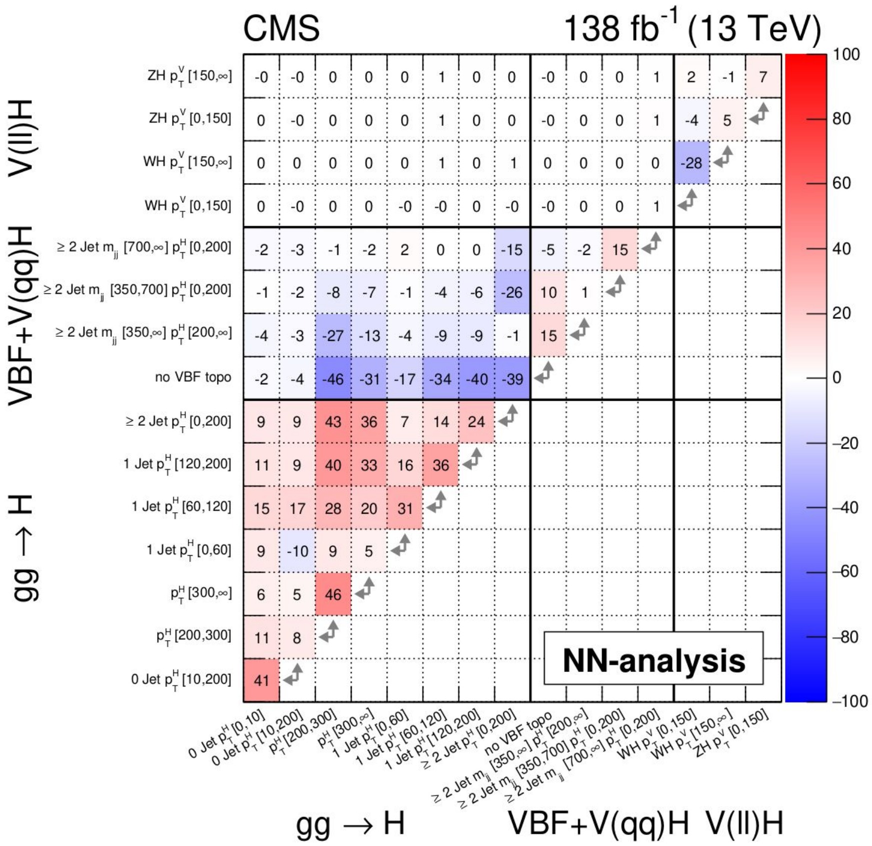
H → ττ STXS Results

STXS Stage 1.2 measurement performed in a total of 16 STXS bins

Up to 40% anticorrelation between VBF with less and two jets and similar ggH categories

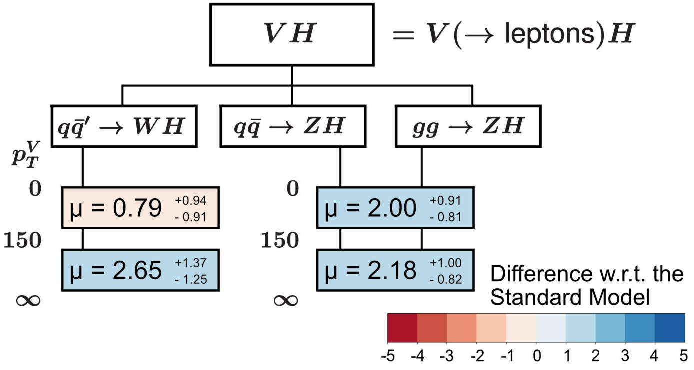
No correlation between VH and ggH/qqH

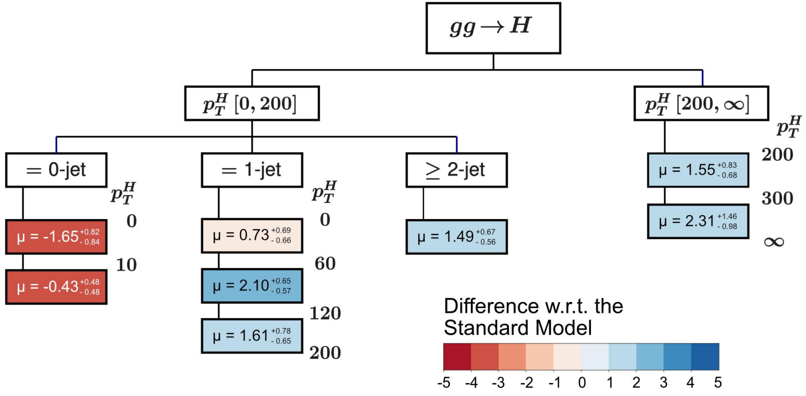
In total: 8 ggH + 4 VBF + 4 VH STXS bins measured

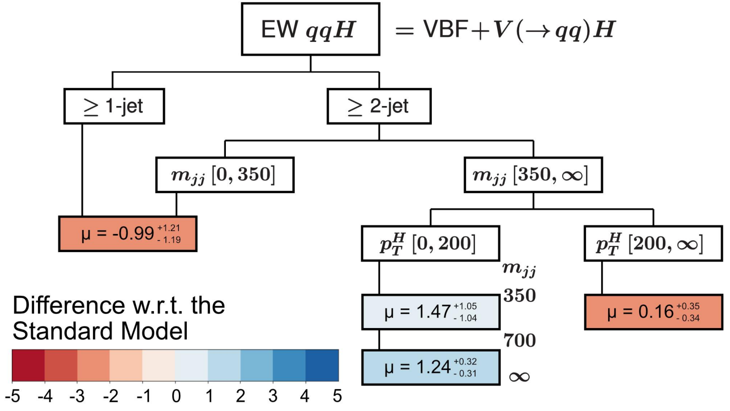


2204.12957

H → ττ STXS Results







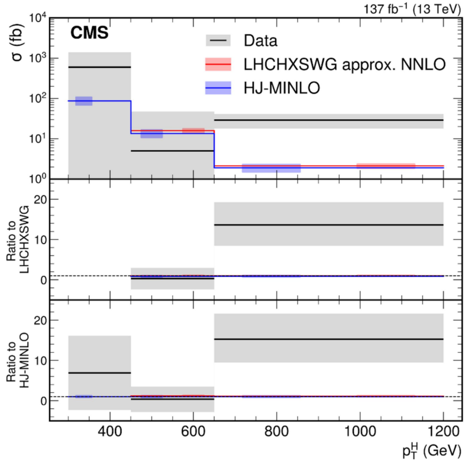
In total: 8 ggH + 4 VBF + 4 VH STXS bins measured

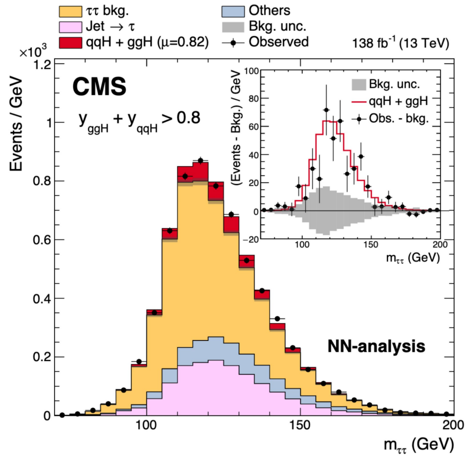
Summary

Two STXS measurements and one differential measurement in fermionic final states presented

- H →bb (boosted ggH)
- H → ττ (differential)
- H → ττ (ggh, VBF, VH)

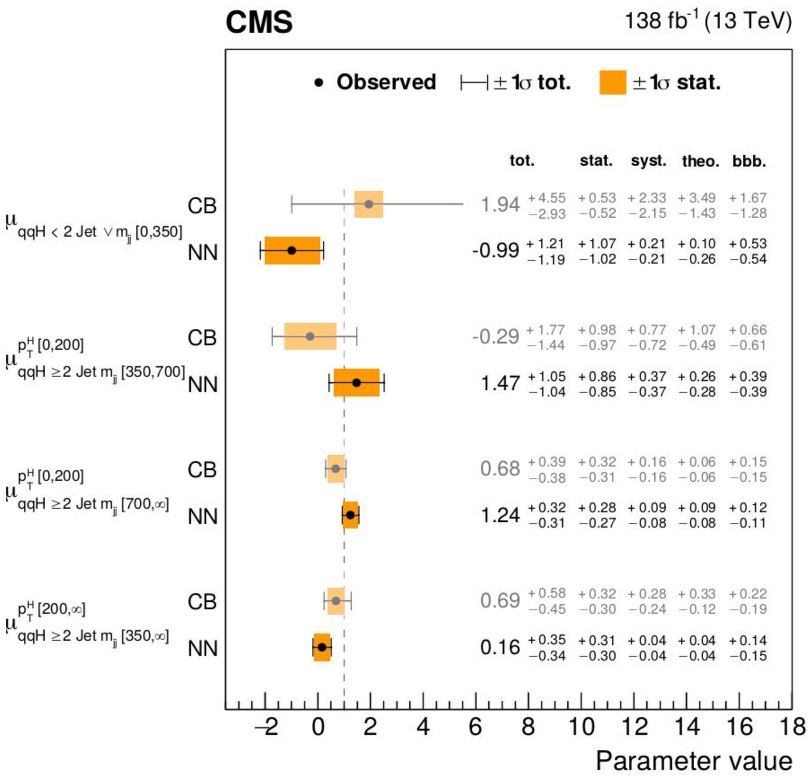
More results can be expected soon !

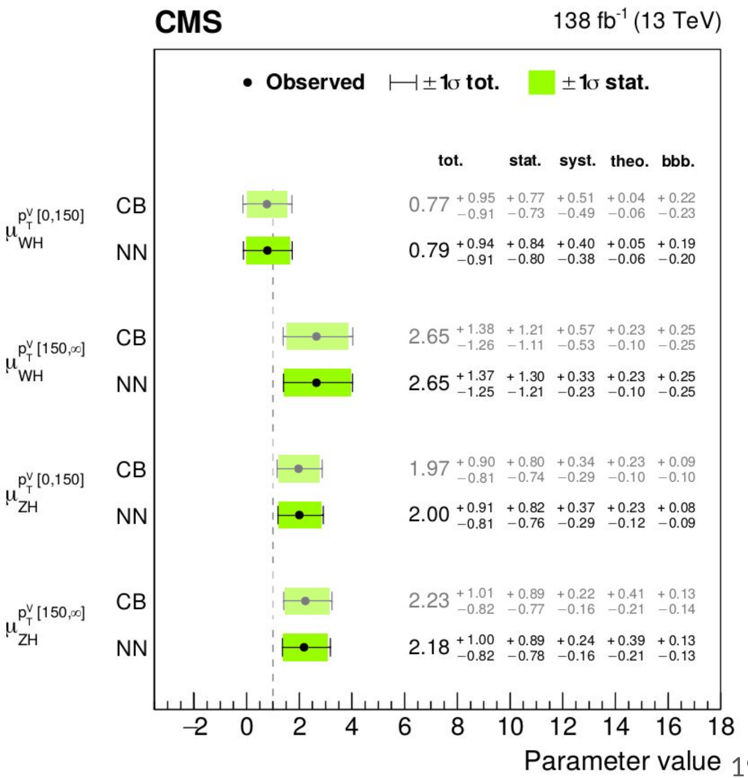




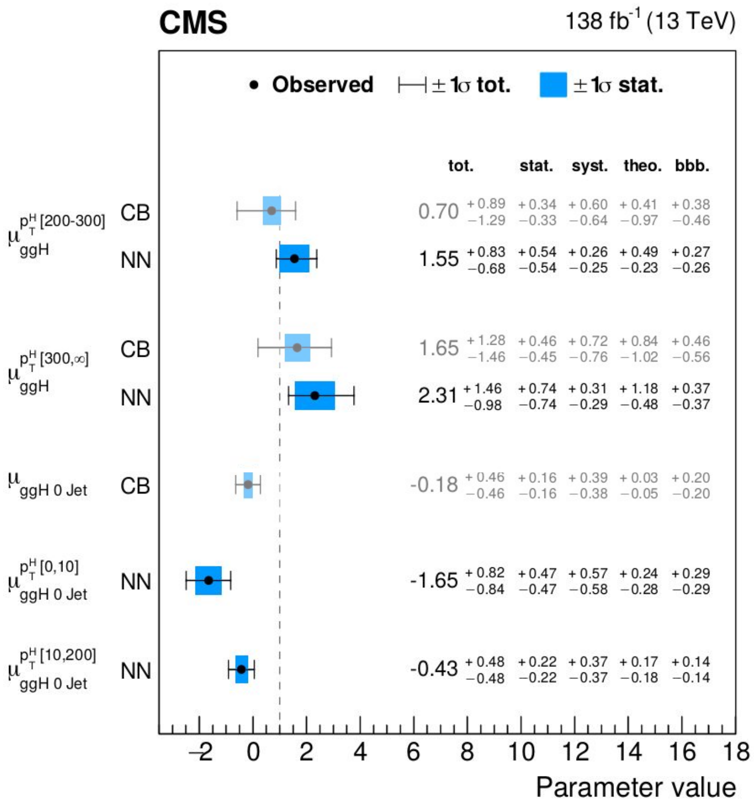
Backup

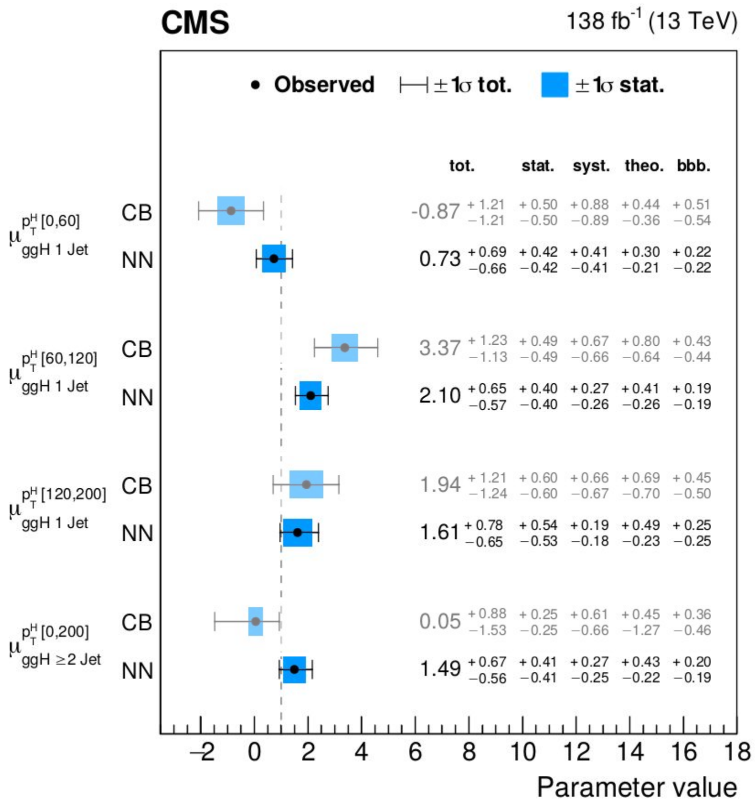
H → ττ Results STXS Stage-1.2



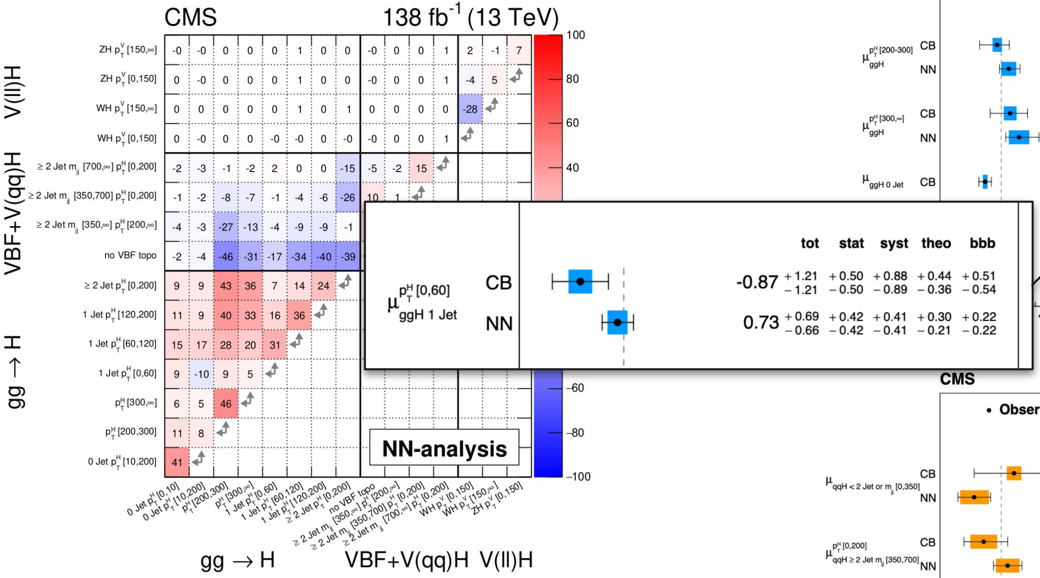


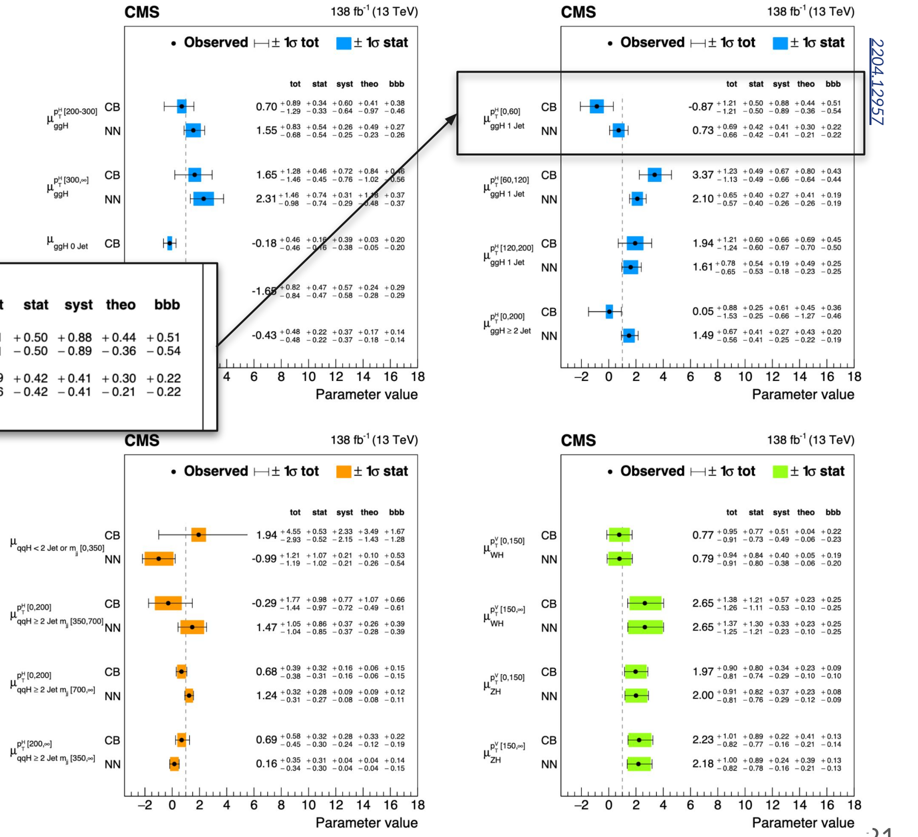
H → ττ Results STXS Stage-1.2





H → ττ STXS Results



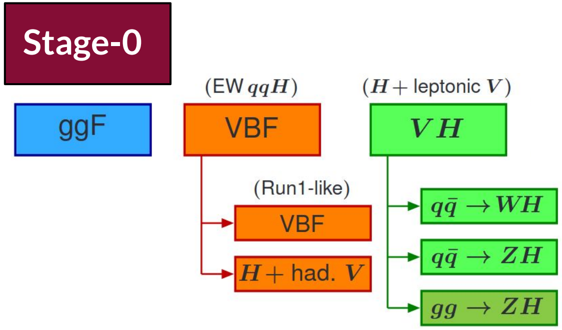


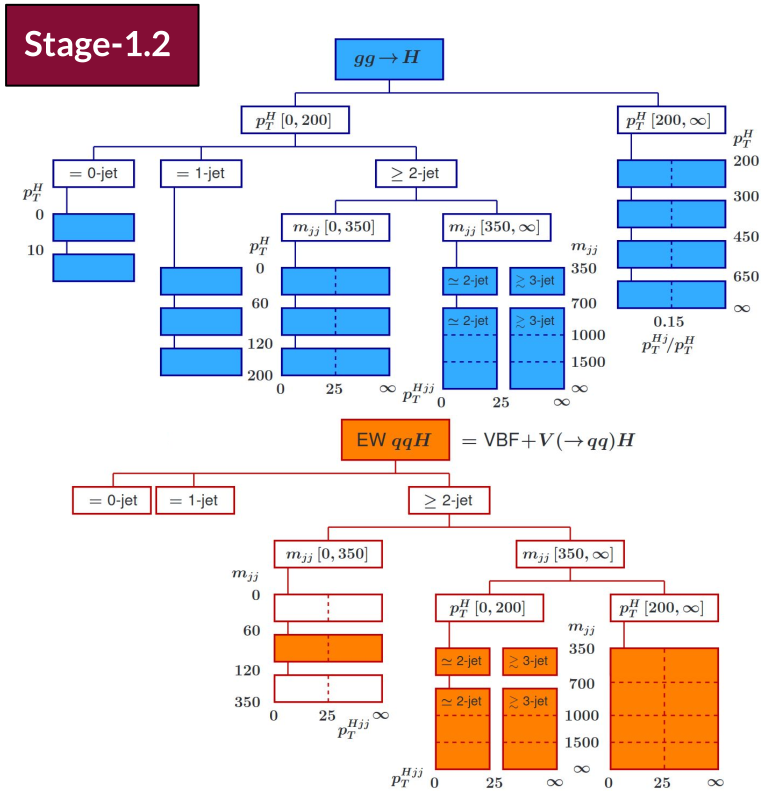
In total: 8 ggH + 4 VBF + 4 VH STXS bins measured

Simplified Template Cross Section Scheme

During Run I, CMS, ATLAS and theorists started an **effort to coordinate differential measurements** between **experiment** and **theory**

- Common scheme of phase space regions
- Reduced dependence on theory / model uncertainties
- Designed for measurement of cross sections rather than signal strengths





Tau decays

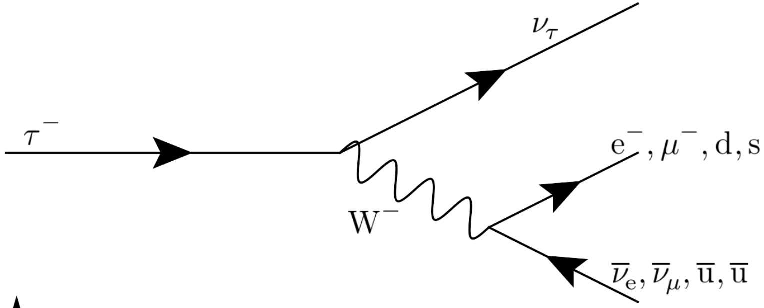
The tau lepton is the only lepton heavy enough (1.7 GeV) to decay into hadrons

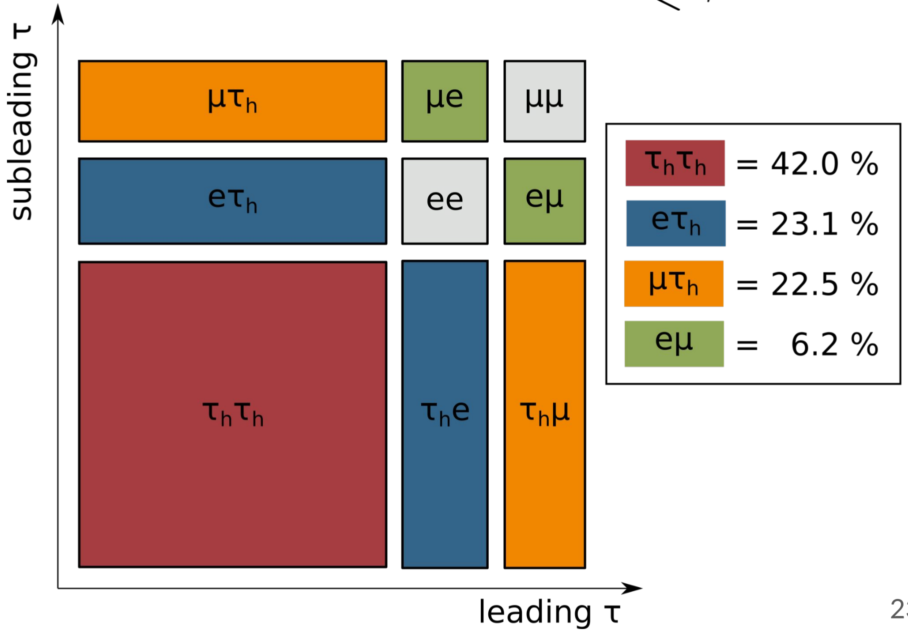
Tau leptons decay into

- 65% - Pions and Kaons (hadronic decay τ_h)
- 35% - Electrons and Muons

+ neutrinos

In **di-tau** analyses, this results in **six** final states, of which **four** are used in the analysis



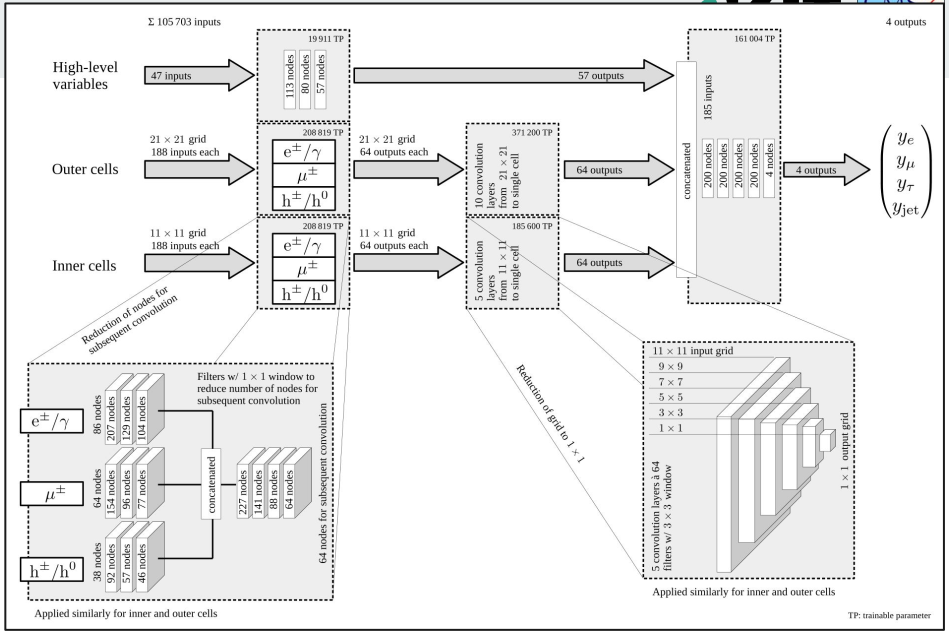


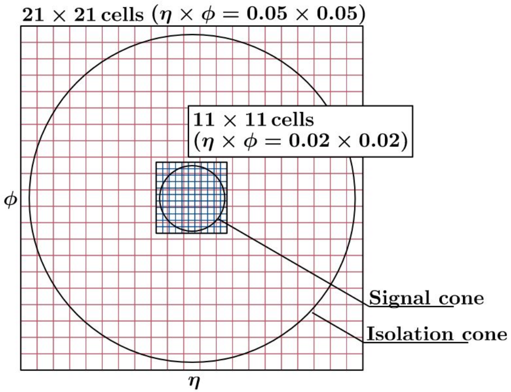
Tau Tagging: DeepTau

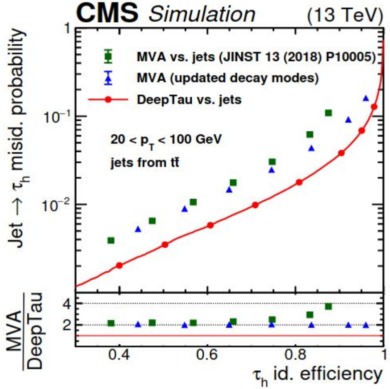
DeepTau is a **deep neural network** (DNN) used to **discriminate** τ_h against **electrons**, **muons** and **jets** within a single architecture [2201.08458]. Two types of input features:

- **High-level variables** like τ_h **momentum**, **charge**, number of charged particles used to reconstruct the τ_h, or **isolation** variables
- **Low-level variables of PF candidates in a grid around the** τ_h axis, split into inner and outer cells.

Improvement between 10%-30% in efficiency at identical misidentification probability

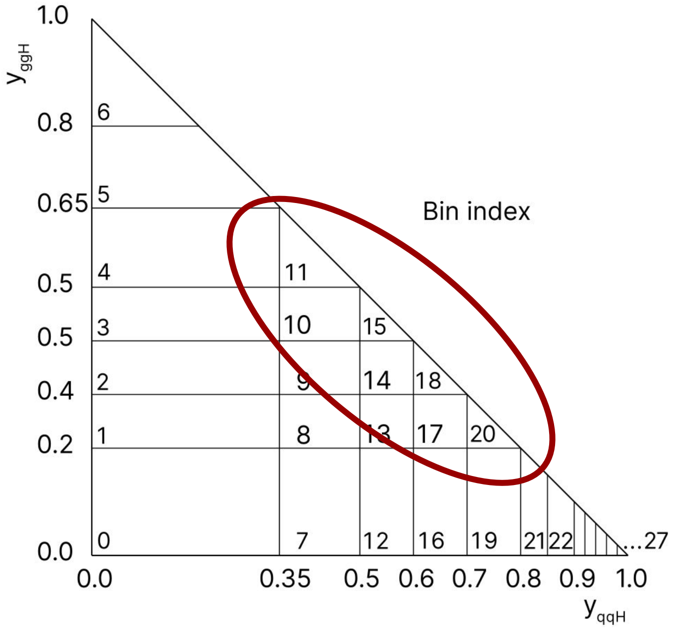


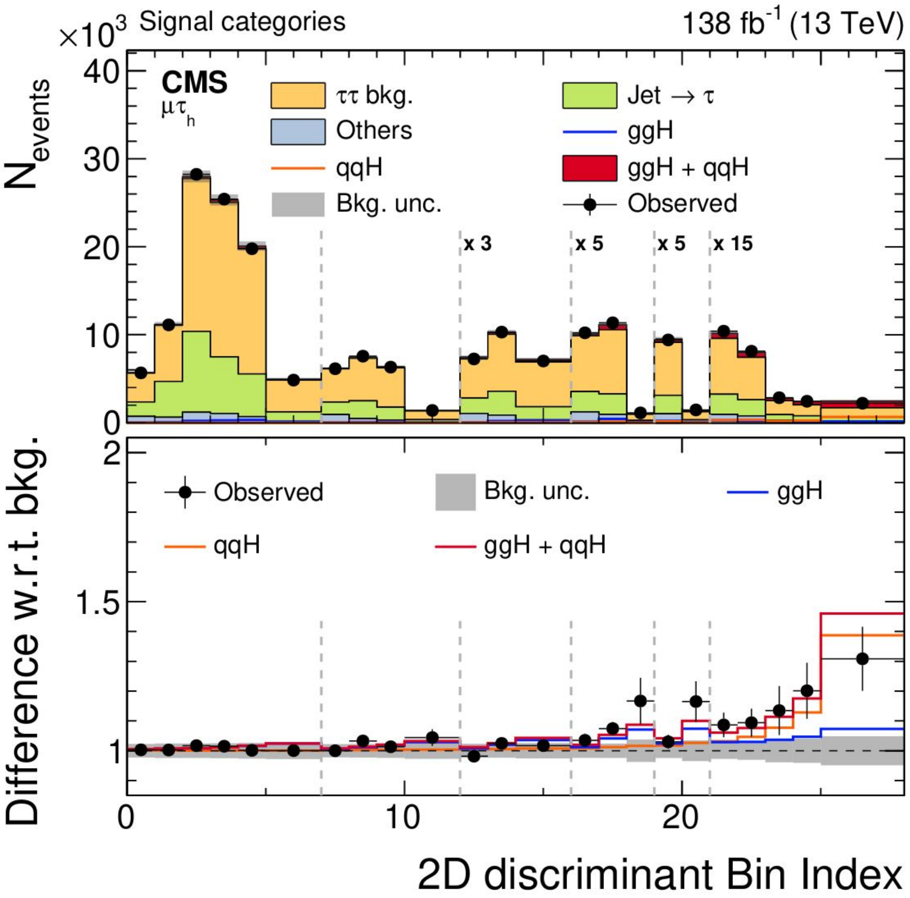




Stage-0 Signal Extraction

For the stage-0 measurement, a 2D discriminator constr



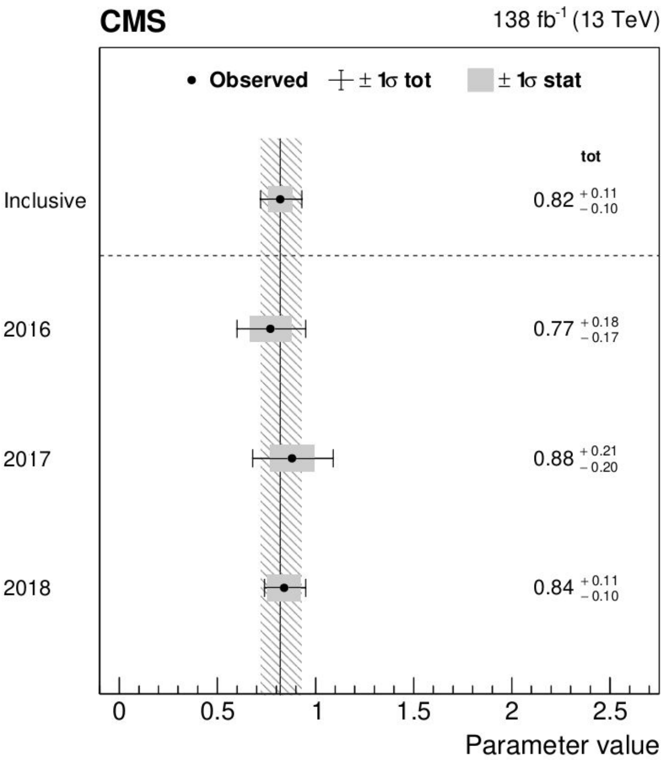


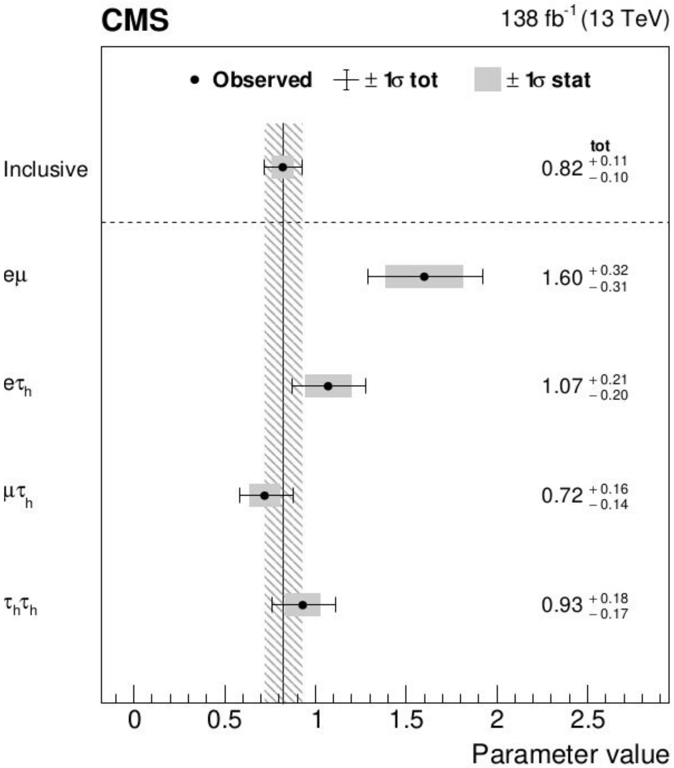
Compatibility of the results

No era dependence visible

eτ_h, $\mu\tau_h$, $\tau_h\tau_h$ are fully compatible with the combined result

eμ shows a ~2 σ deviation from the combined result



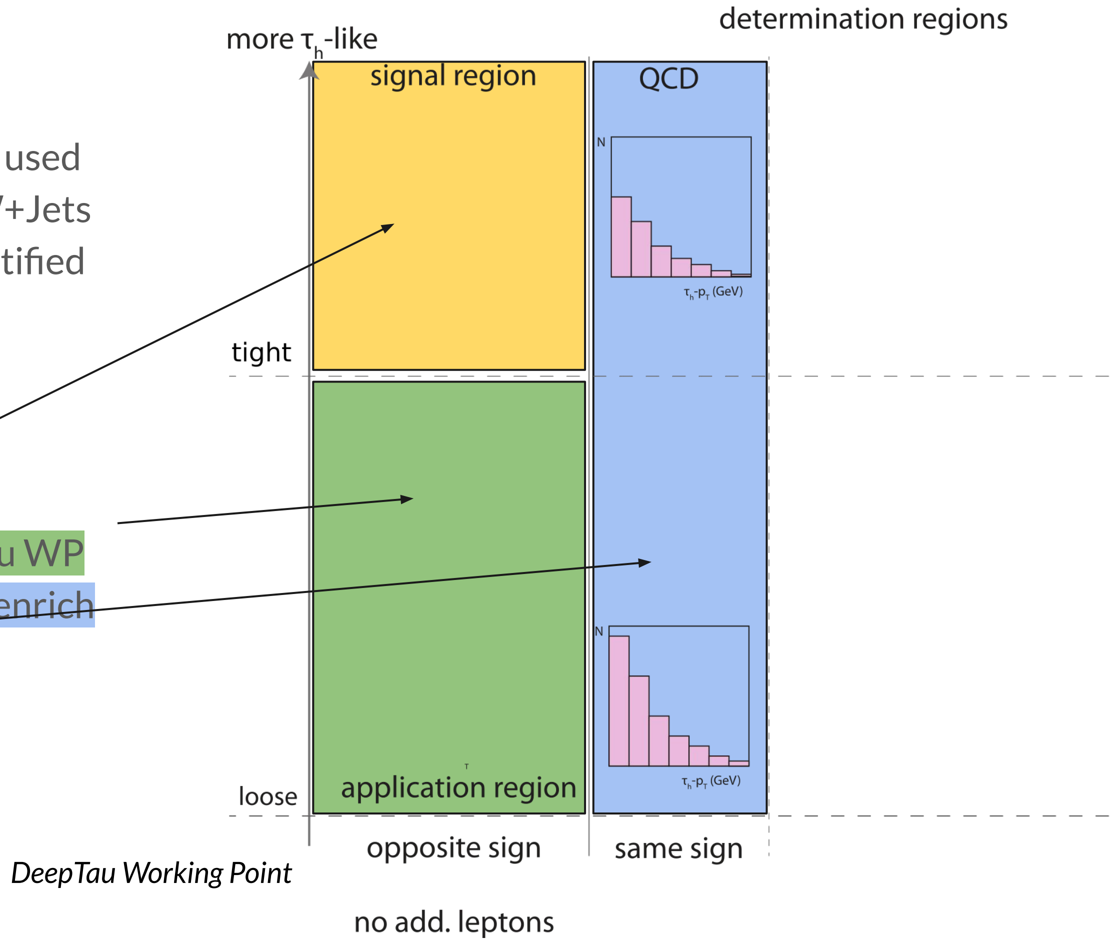


F_F Method

F_F method is a **sideband region** method used to estimate contributions from QCD, W+Jets and tt production where a jet is misidentified as a τ_h

Three different regions:

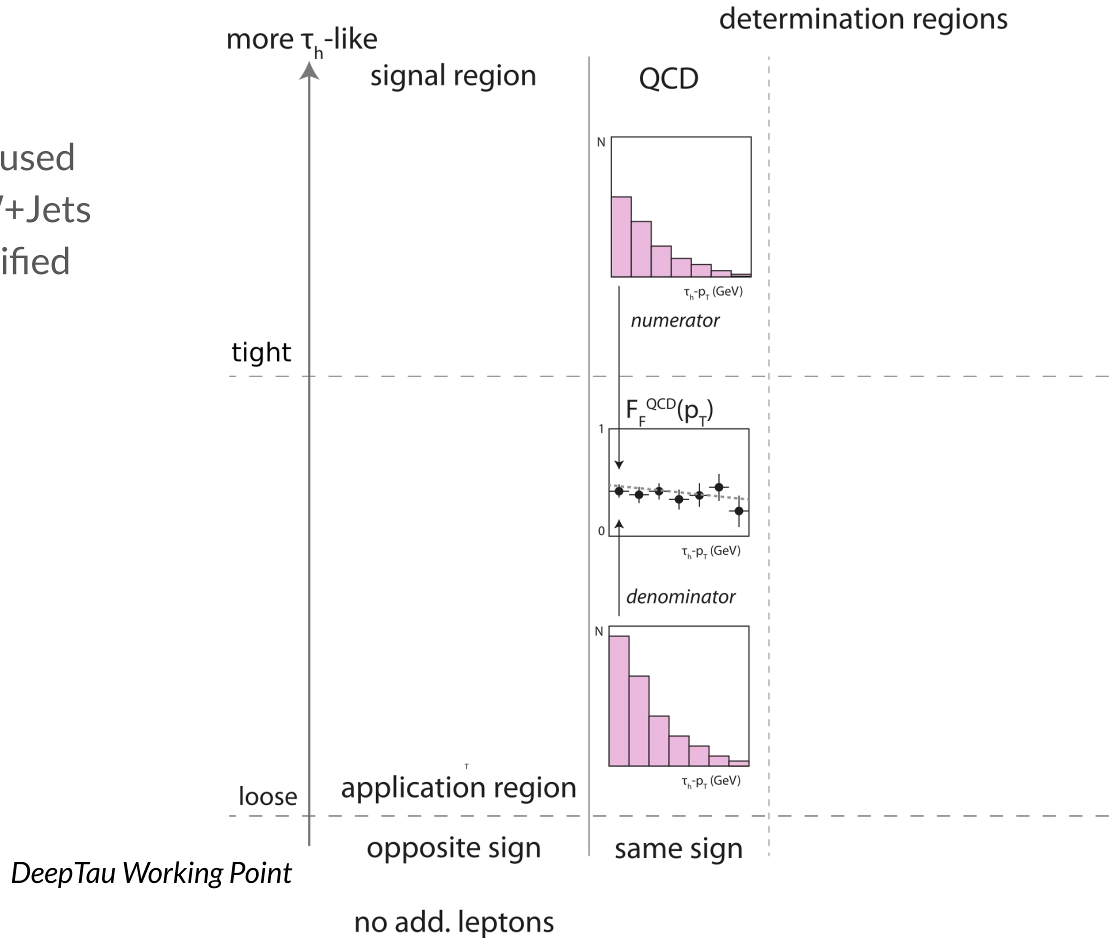
SR - **signal region** of the analysis
AR - **application region** with a looser tau WP
DR - **determination region**, a region to enrich the process (e.g. same sign for QCD)



F_F Method

F_F method is a sideband region method used to estimate contributions from QCD, W+Jets and tt production where a τ_h is misidentified as a jet

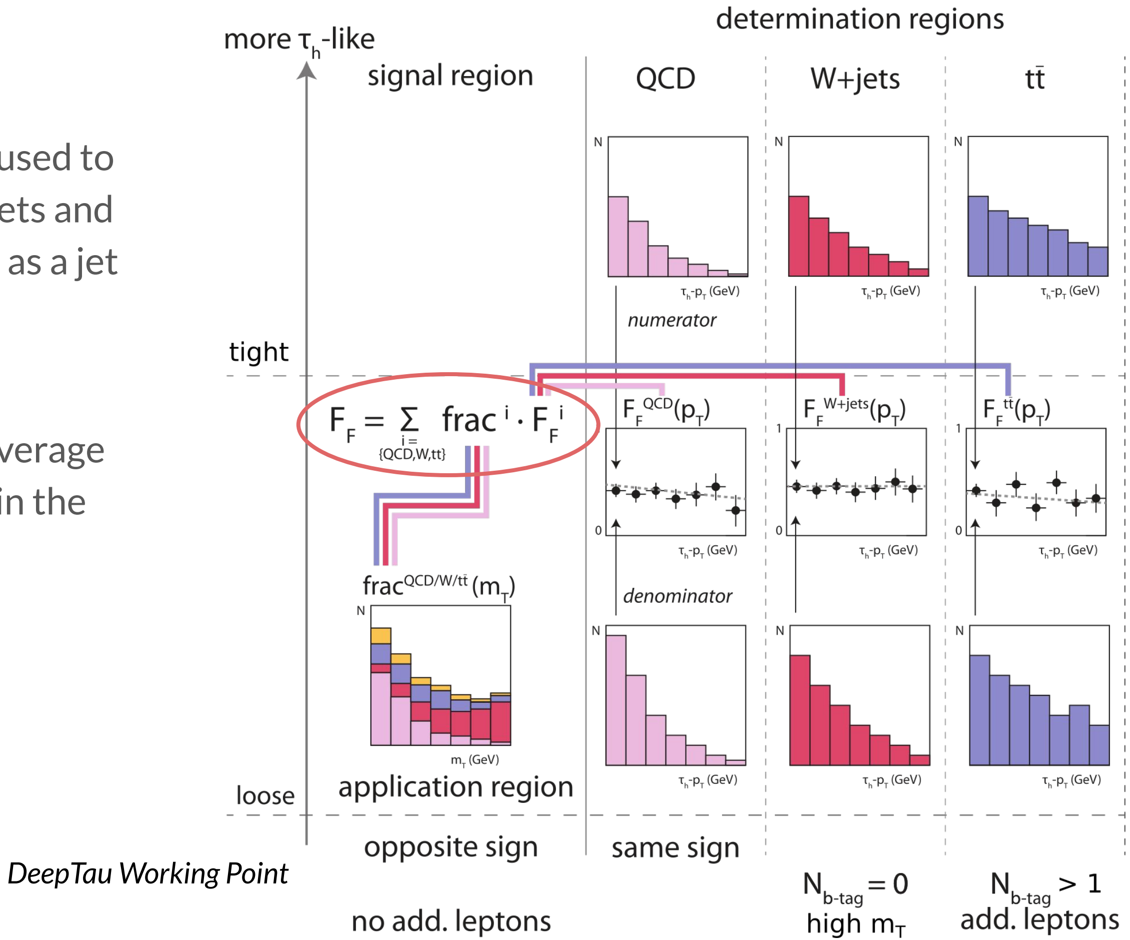
Determine F_F for QCD by dividing the contributions of QCD events in the determination region in the `tight` and `!tight` && `loose` region



F_F Method

F_F method is a sideband region method used to estimate contributions from QCD, W+Jets and tt production where a τ_h is misidentified as a jet

Determine the total F_F from weighted average of the individual F_F based on their yield in the AR



F_F Method

F_F method is a sideband region method used to estimate contributions from QCD, W+Jets and tt production where a τ_h is misidentified as a jet

Determine contribution from τ_h misidentified as jets by multiplying the total F_F with the total number of events in the AR