Study of the Higgs boson Yukawa coupling to leptons

Sergi Rodríguez Boscà

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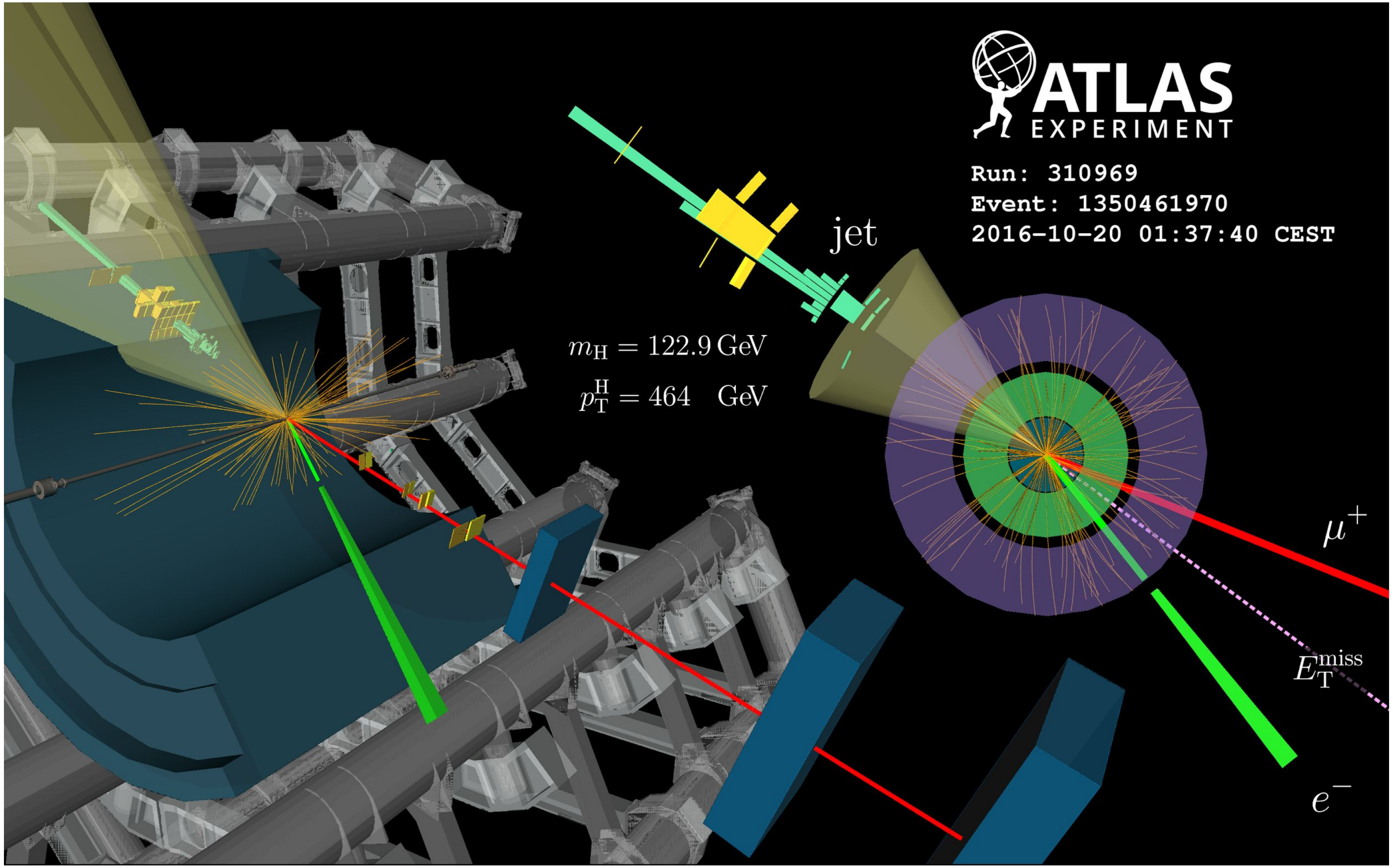
Outline

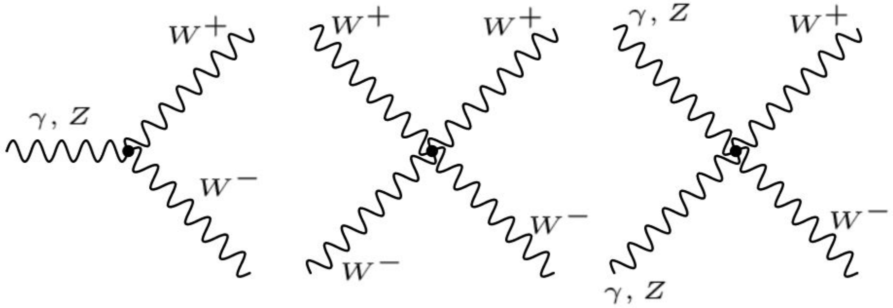
1. Introduction
2. H$\longrightarrow$ ττ analysis
3. H $\longrightarrow$ τℓ search
4. Conclusions



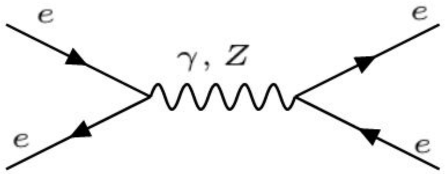
The SM and the Higgs sector

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \bar{\psi}_i y_{ij}\psi_j\phi + h.c. + |D_\mu\phi|^2 - V(\phi)$$

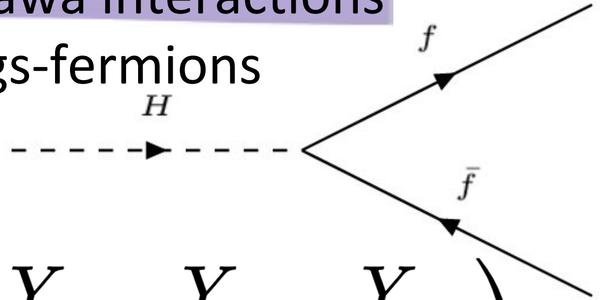
Kinetic energies and self-interactions of the gauge bosons



Kinetic energies and weak interactions of fermions



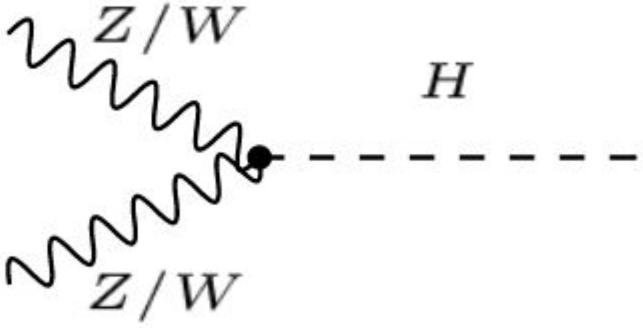
Yukawa interactions Higgs-fermions



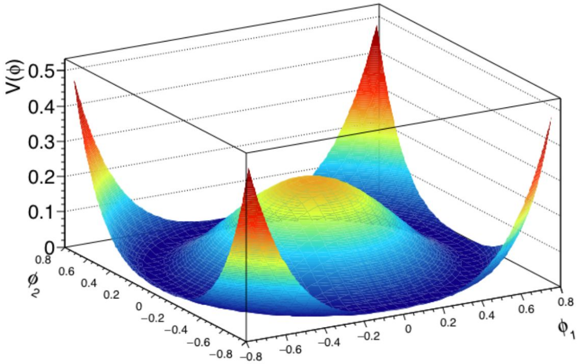
$$\begin{pmatrix} Y_{ee} & Y_{e\mu} & Y_{e\tau} \\ Y_{\mu e} & Y_{\mu\mu} & Y_{\mu\tau} \\ Y_{\tau e} & Y_{\tau\mu} & Y_{\tau\tau} \end{pmatrix}$$

Off-diagonal terms are 0 for the SM

Standard interactions with the gauge bosons

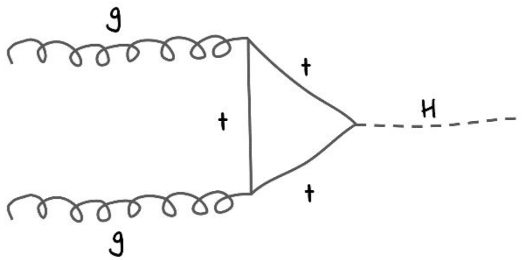


Potential of the Higgs field

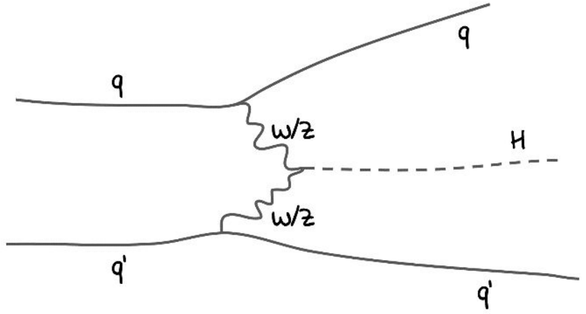


Introduction

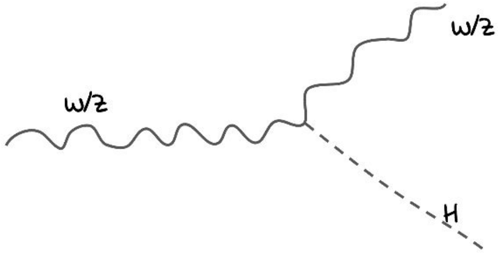
The most important productions in the LHC at 13 TeV for the Higgs boson are



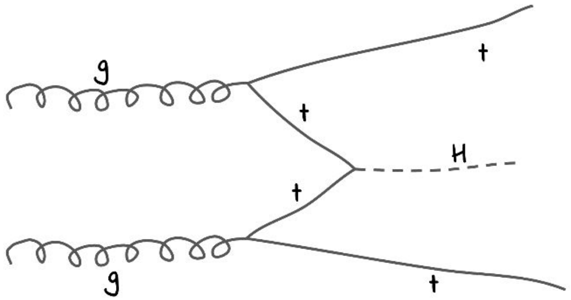
ggF (86%)



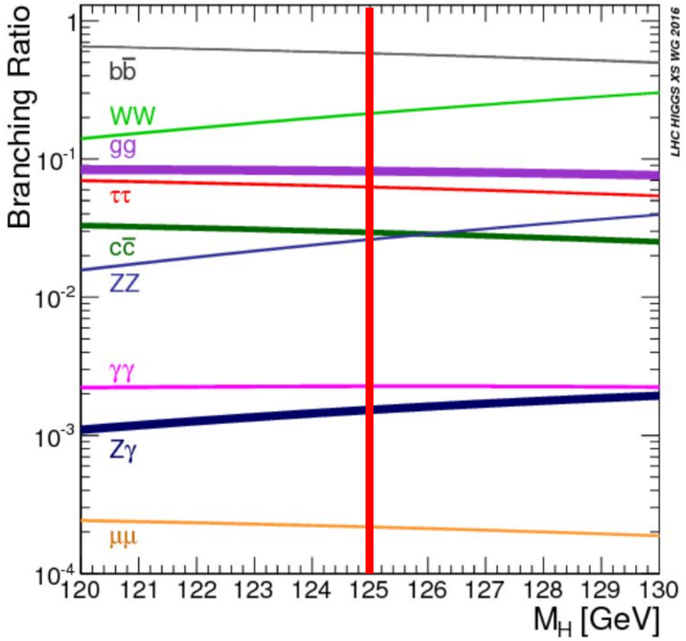
VBF (7%)



VH (4%)



ttH (1%)



$m_H = 124.97 \pm 0.24$ GeV

There are different possibilities in the Higgs boson to lepton decays:

- the Standard Model expected decays:

$$H \to \tau\tau,\ H \to \mu\mu,\ H \to ee$$

- new possible physics signatures → Lepton Flavour Violation (LFV)

$$H \to \mu\tau,\ H \to e\tau,\ H \to e\mu$$

Hττ analysis

The analysis of the Higgs boson decaying into a pair of τ-leptons focuses on the measurement of the total cross-section and the measurement of the cross-section per individual channel using 36 fb^{-1} of data.

$$\sigma_{H\to\tau\tau} = \sigma_H \cdot \mathcal{BR}(H \to \tau\tau)$$

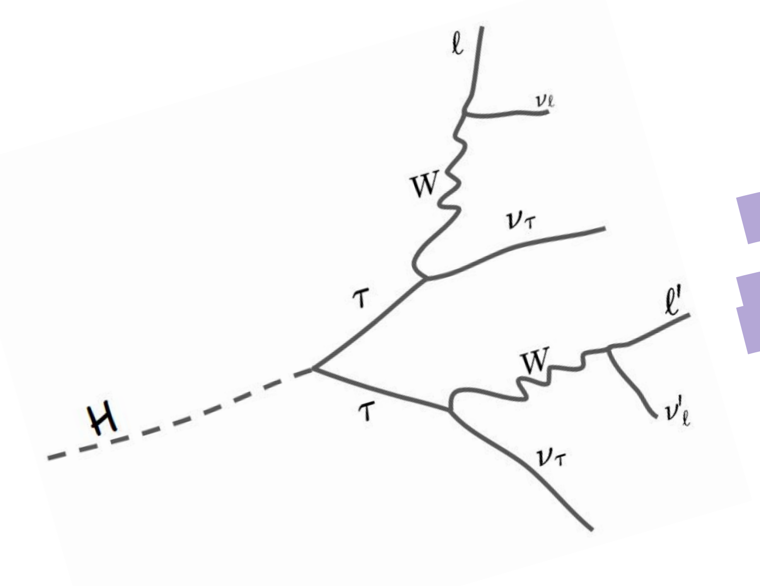
The τ-lepton has two different decay modes: τ_{lep} or τ_{had} .

All combinations of leptonic (τ→$\ell\nu\nu$ with ℓ= e, μ) and hadronic tau decays (τ→had+ν) are considered in the analysis.

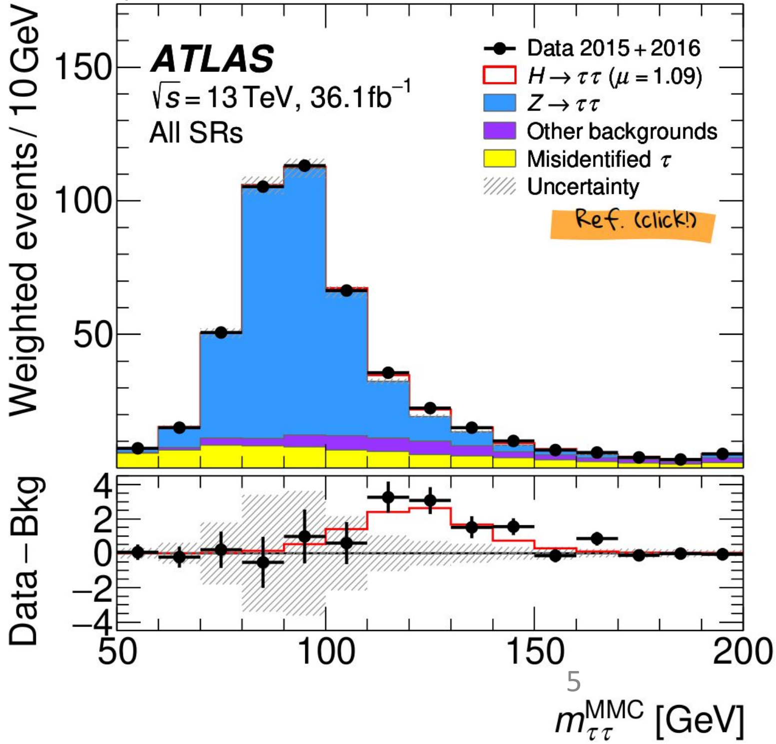
$\tau_{\text{lep}}\tau_{\text{lep}}$

$\tau_{\text{lep}}\tau_{\text{had}}$

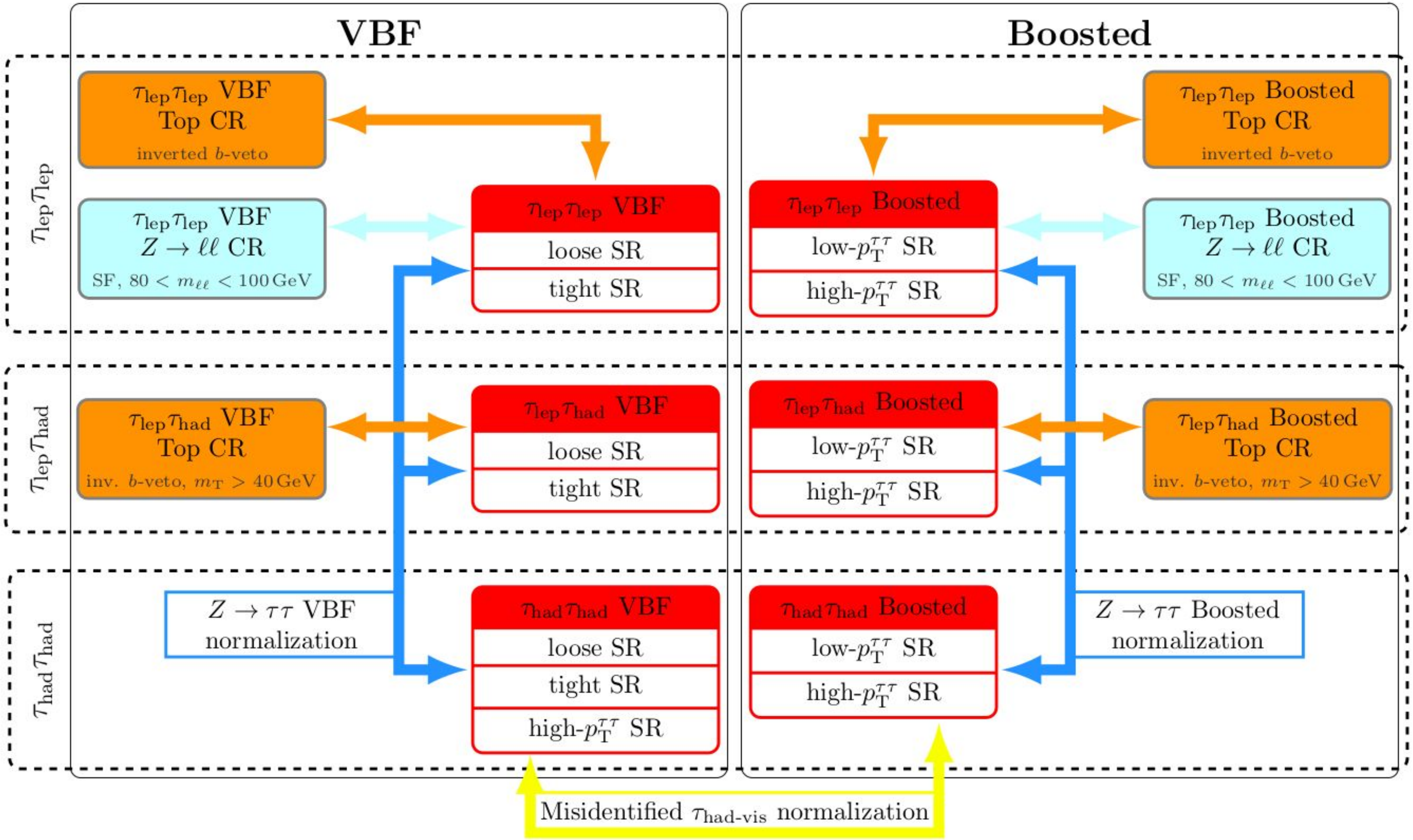
$\tau_{\text{had}}\tau_{\text{had}}$



The less sensitive channel is the $\tau_{\text{lep}}\tau_{\text{lep}}$ because the 33% of time the tau decays leptonically.



Analysis categories



Results

Ref. (click!)

Three different fits have been done to measure the $H \to \tau\tau$ cross-section in different ways.

Firstly, the total cross section is measured with a 4.4σ for Run 2 (6.4σ combining the results with Run 1)

$$\sigma_{H\to\tau\tau} = 3.77^{+0.60}_{-0.59}(\text{stat})^{+0.74}_{-0.87}(\text{syst})\ \text{pb} \quad (\varepsilon_r \sim 25\%) \quad \text{vs} \quad \sigma^{\text{SM}}_{H\to\tau\tau} = 3.43 \pm 0.13\ \text{pb}$$

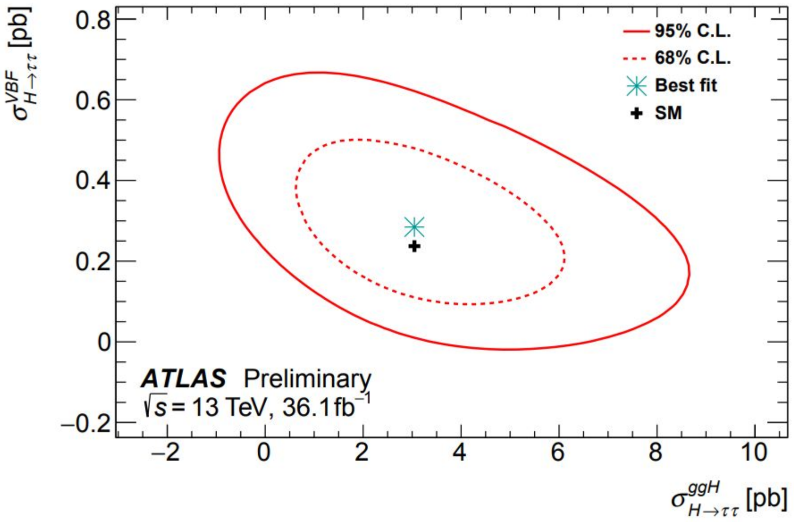
The signal strength obtained is:

$$\frac{\sigma_{H\to\tau\tau}}{\sigma^{\text{SM}}_{H\to\tau\tau}} = \mu_{H\to\tau\tau} = 1.09^{+0.18}_{-0.17}(\text{stat})^{+0.27}_{-0.22}(\text{syst})^{+0.16}_{-0.11}(\text{theory syst}) \quad (\varepsilon_r \sim 30\%)$$

Run 1 results:

$$\mu^{\tau\tau}_{\text{ATLAS}} = 1.43\ ^{+0.43}_{-0.37}$$

$$\mu^{\tau\tau}_{\text{CMS}} = 0.86 \pm 0.29$$



The cross-section for the main production mode of the Higgs boson decaying to tau-leptons are:

$$\sigma^{\text{ggF}}_{H\to\tau\tau} = 3.1 \pm 1.0(\text{stat})^{+1.3}_{-1.6}(\text{syst})\ \text{pb} \qquad \sigma^{\text{SM}}_{\text{ggF},\ H\to\tau\tau} = 3.05 \pm 0.13\ \text{pb}$$

vs

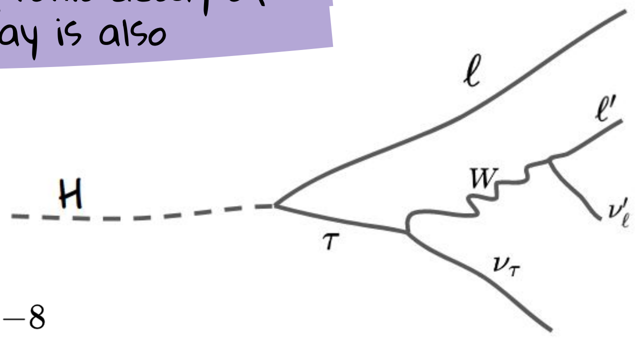
$$\sigma^{\text{VBF}}_{H\to\tau\tau} = 0.25 \pm 0.09(\text{stat})^{+0.11}_{-0.09}(\text{syst})\ \text{pb} \qquad \sigma^{\text{SM}}_{\text{VBF},\ H\to\tau\tau} = 0.237 \pm 0.006\ \text{pb}$$

LFV search

The lepton flavour violation searches are focused to find and excess over the background expectation:

- $H \to \mu\tau$ → commonly MUE channel
- $H \to e\tau$ → commonly EMU channel

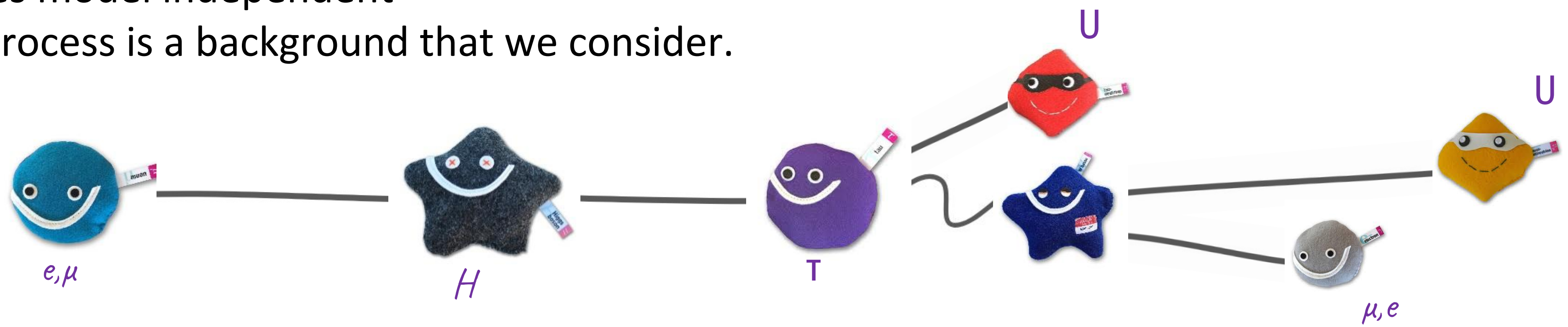
My work was based on the leptonic decay of the tau, but the hadronic decay is also considered



The bounds on the LFV couplings were all indirect

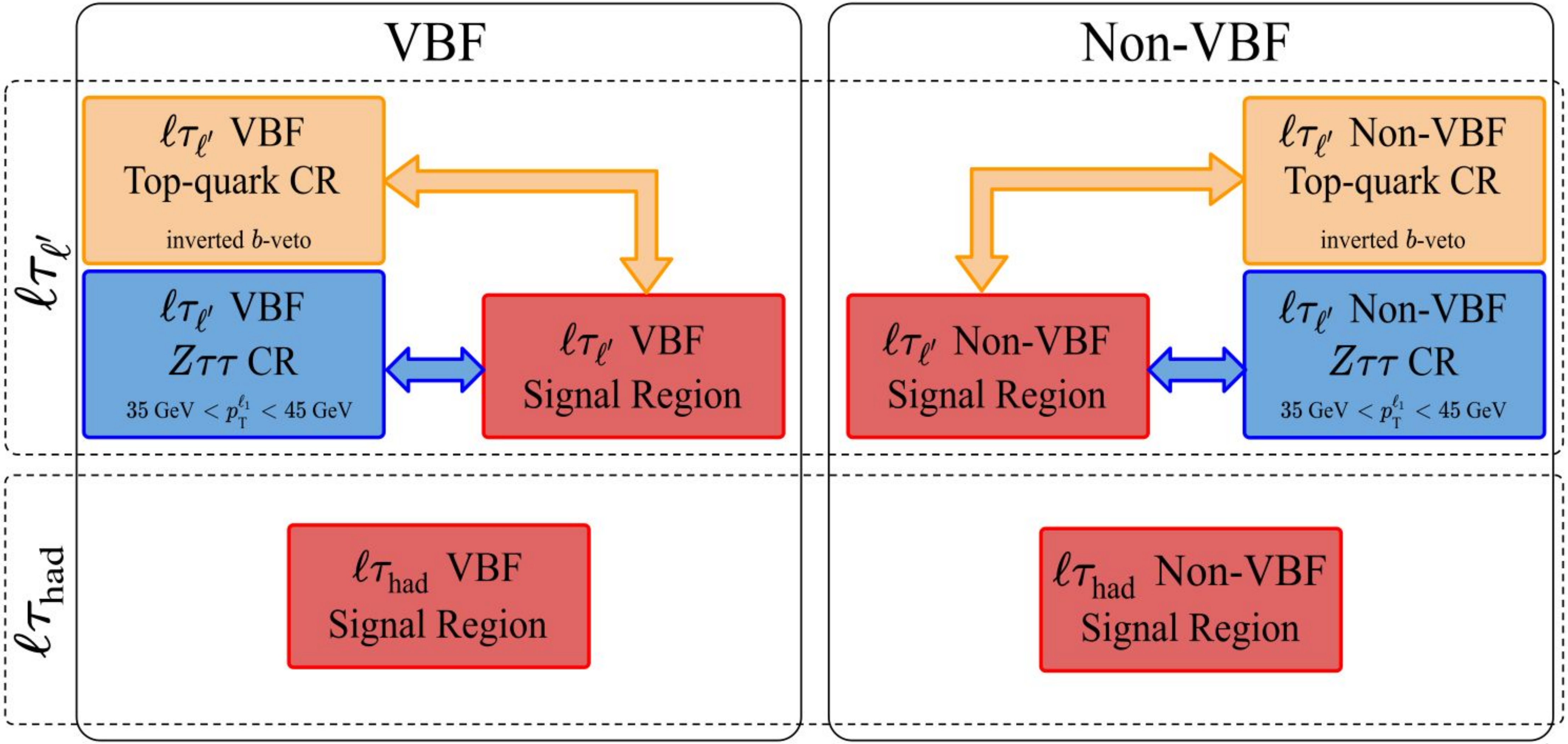
- Limit on the $Y_{e\mu}$ by null evidence of $\mu \to e\gamma$ decay, $BR(H \to e\mu) < 10^{-8}$
- However, $Y_{\tau e}$ and $Y_{\tau\mu}$ are much less stringent allowing an upper limit on the $BR(H \to \ell\tau) < \mathcal{O}(1\%)$ found in previous ATLAS and CMS searches

Both searches model independent
The H⟶ ττ process is a background that we consider.



Analysis categories

The events can enter in two different signal regions, after passing a preselection:



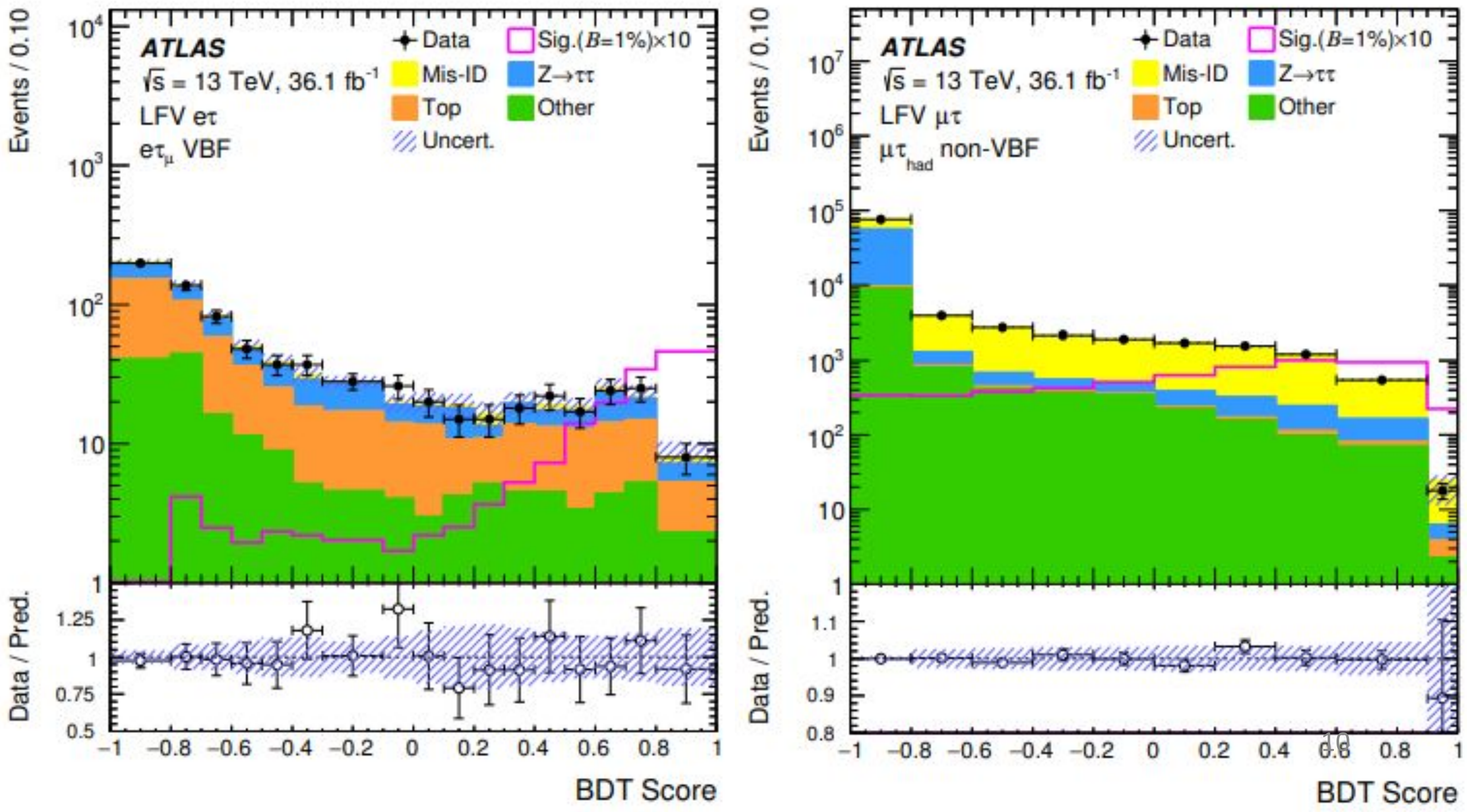
MVA

To improve the sensitivity in the signal regions, a MultiVariate Analysis (MVA) is used to separate further the signal-like events from the background-like events using Boosted Decision Trees (BDTs).

- Two BDTs have been trained, one for each SR

Simulated events are splitted into 80% of training and 20% of testing

	1	2	3	4	5
k=1					
2					
3					
4					
5					



Results

Ref. (click!)

The best fit values of the LFV decay branching ratios of the Higgs boson are

$$\mathcal{BR}(H \to \tau e) = 0.15^{+0.18}_{-0.17}\%$$

$$\mathcal{BR}(H \to \tau \mu) = -0.22 \pm 0.19\%$$

	95% CL upper limits	
	$\mathcal{BR}(H \to \tau e)[\%]$	$\mathcal{BR}(H \to \tau \mu)[\%]$
ATLAS Run 1	1.04	1.43
ATLAS Run 2	0.47	0.28
CMS($35.9\ \mathrm{fb}^{-1}$)	0.61	0.25

Results are compatible with zero, hence upper limits are set:

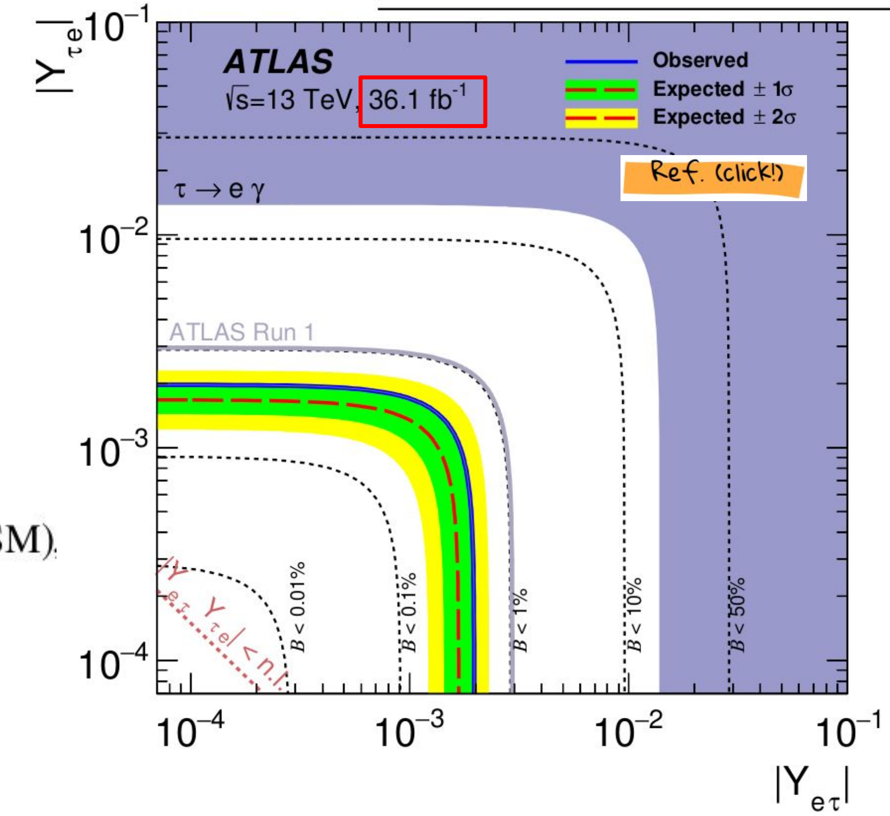
$$CL_S = \frac{p_{S+B}}{1-p_B}$$

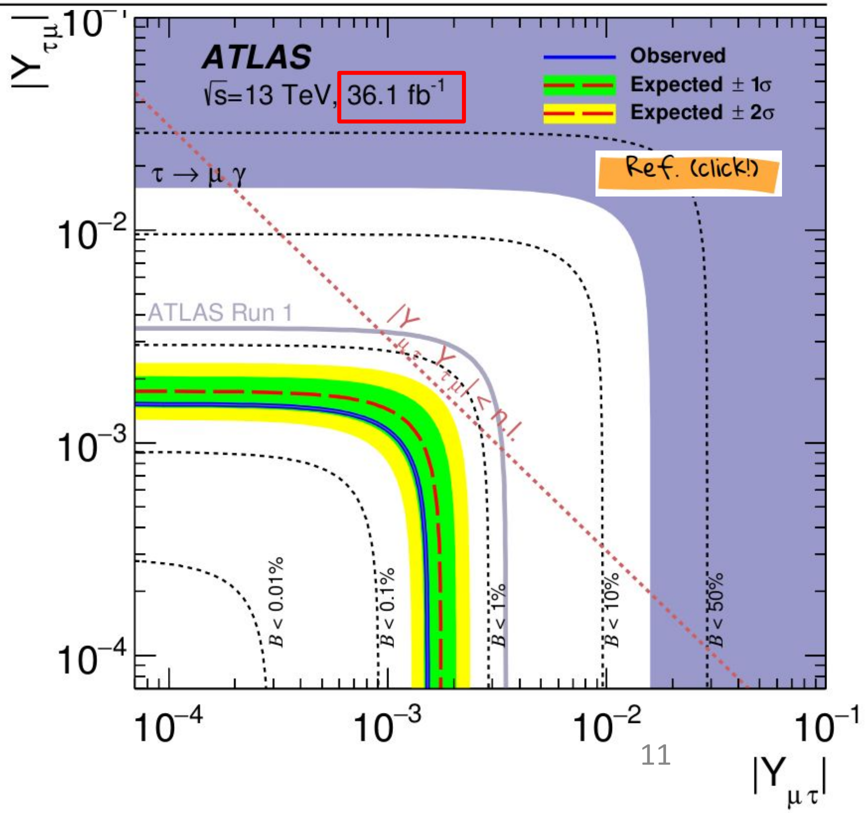
The Yukawa couplings are related with the branching fractions:

$$\sqrt{|Y_{\ell\tau}|^2 + |Y_{\tau\ell}|^2} = \frac{8\pi}{m_H}\frac{\mathcal{B}(H \to \ell\tau)}{1-\mathcal{B}(H \to \ell\tau)}\Gamma_H(\mathrm{SM}).$$

$$\sqrt{|Y_{\tau e}|^2 + |Y_{e\tau}|^2} < 0.0020$$

$$\sqrt{|Y_{\tau\mu}|^2 + |Y_{\mu\tau}|^2} < 0.0015$$





Yukawa coupling to leptons

Up-to-date results:

Search	ATLAS		CMS	
H→ ττ	(Link, $36\,fb^{-1}$)	$\mu_{H\to\tau\tau} = 1.09^{+0.36}_{-0.30}$	(Link, $137\,fb^{-1}$)	$\mu_{H\to\tau\tau} = 0.85^{+0.12}_{-0.11}$
H→ μμ	(Link, $139\,fb^{-1}$)	$\mu_{H\to\mu\mu} = 1.12 \pm 0.6$	(Link, $137\,fb^{-1}$)	$\mu_{H\to\mu\mu} = 1.19^{+0.42}_{-0.41}$
H→ ee	(Link, $139\,fb^{-1}$)	$\mathcal{BR}(H \to ee) < 3.6 \cdot 10^{-4}$	(Link, $19.7\,fb^{-1}$)	$\mathcal{BR}(H \to ee) < 1.9 \cdot 10^{-3}$
H→ μτ	(Link, $36\,fb^{-1}$)	$\mathcal{BR}(H \to \mu\tau) < 0.28$	(Link, $35.9\,fb^{-1}$)	$\mathcal{BR}(H \to \mu\tau) < 0.25$
H→ eτ	(Link, $36\,fb^{-1}$)	$\mathcal{BR}(H \to e\tau) < 0.47$	(Link, $35.9\,fb^{-1}$)	$\mathcal{BR}(H \to e\tau) < 0.61$
H→ eμ	(Link, $139\,fb^{-1}$)	$\mathcal{BR}(H \to e\mu) < 6.2 \cdot 10^{-5}$	(Link, $19.7\,fb^{-1}$)	$\mathcal{BR}(H \to e\mu) < 3.5 \cdot 10^{-4}$

Conclusions

- One direct search (LFV analysis) and one measurement (H$\longrightarrow$ $\tau\tau$ cross-section) of the Yukawa coupling to leptons have been described.
- The searches exploit the most relevant production modes of the Higgs boson (ggF and VBF) optimizing two categories

- For the H$\longrightarrow$ $\tau\tau$ analysis, the total cross-section has been computed as well as the cross-section per Higgs production mode (ggF and VBF)
- The H$\longrightarrow$ $\tau\tau$ results are in agreement with the standard model predictions, with a combined significance of Run 1 and 36 fb^{-1} of Run 2 of 6.4 standard deviations that constitutes an observation of this process by ATLAS.

- For the LFV search, multivariate analysis method has been used to improve the sensitivity in the signal regions.
- Despite the lack of LFV observations, strong upper limits have been obtained compared with the previous ATLAS values.

Backup