Andrea Cardini

on behalf of the CMS collaboration

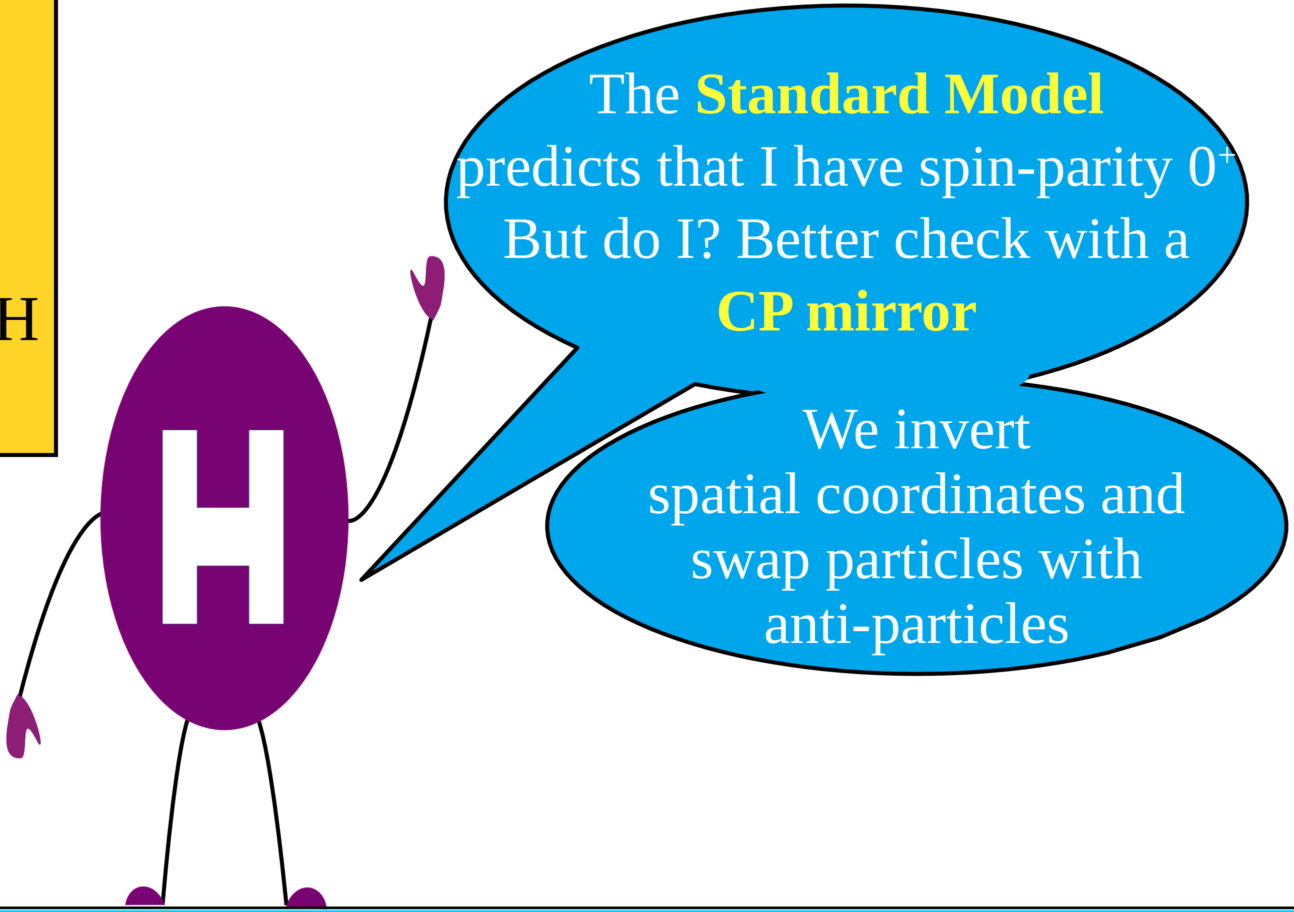
The Higgs through the looking glass.

Measurement of the CP structure of the Yukawa interaction in Higgs boson decays to τ leptons in CMS

Introduction

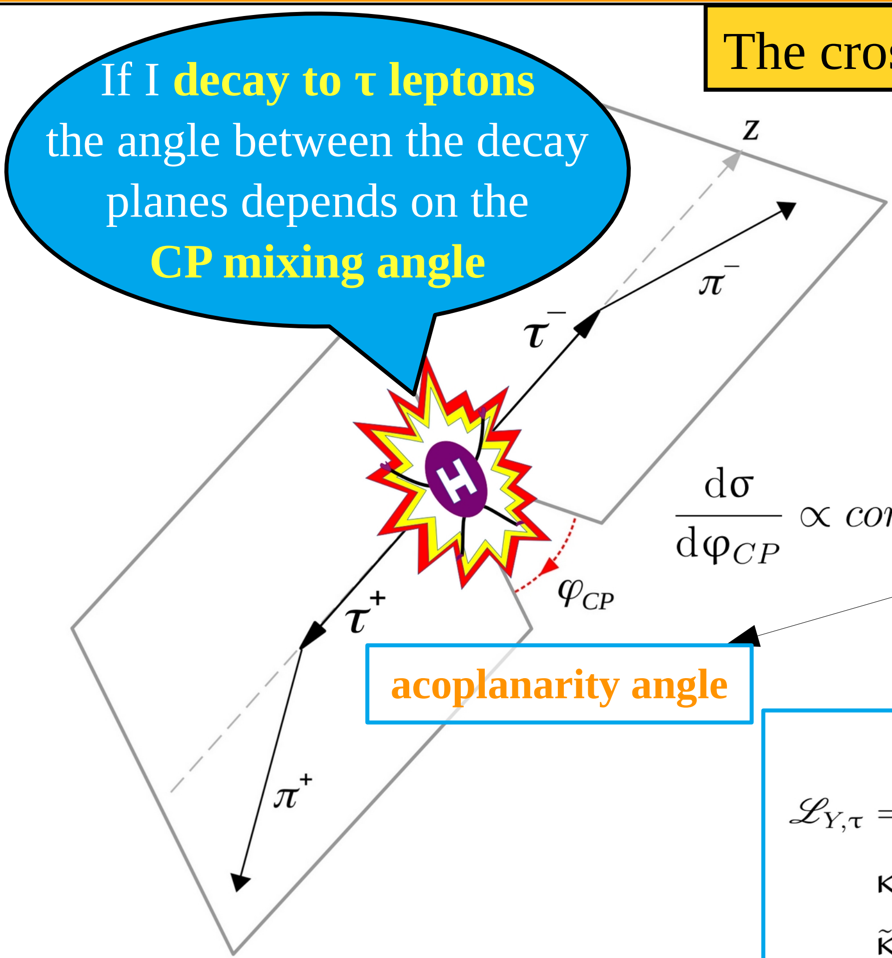
CP-violation in the Higgs couplings can occur in:

- HVV couplings
- Yukawa coupling:
  - Production via ttH and ggH
  - **Decays into τ leptons**



The acoplanarity angle

The cross-section of the H → ττ process has a sinusoidal shape



CP even	$\varphi_{\tau\tau} = 0°$
CP mix	$\varphi_{\tau\tau} = 45°$
CP odd	$\varphi_{\tau\tau} = 90°$

$$\frac{d\sigma}{d\varphi_{CP}} \propto const - \cos\left(\boxed{\varphi_{CP}} - 2\boxed{\varphi_{\tau\tau}}\right)$$

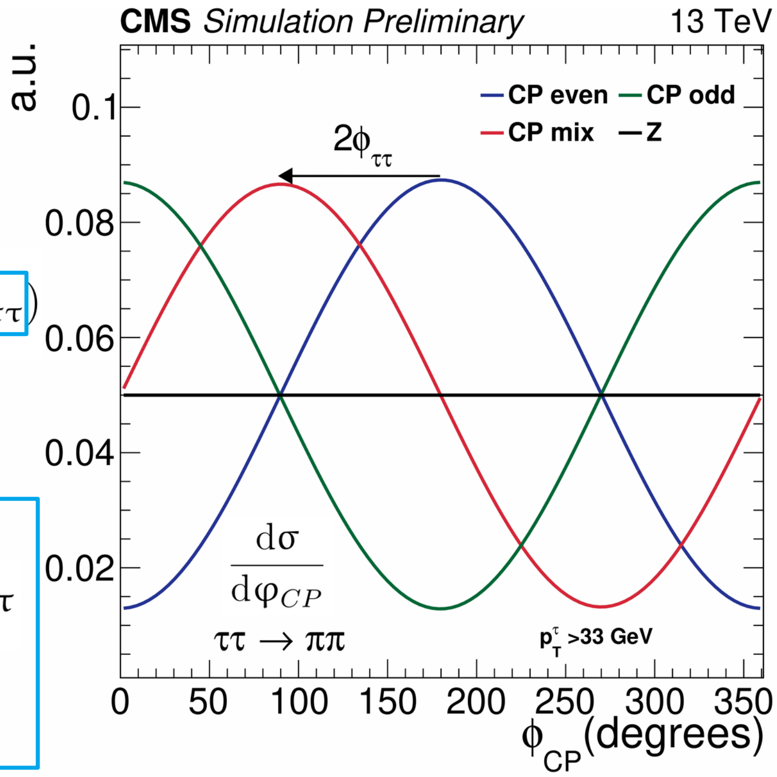
acoplanarity angle

CP mixing angle

$$\mathscr{L}_{Y,\tau} = -\frac{m_\tau}{v}\,\bar{\tau}(\kappa_\tau + i\gamma^5\tilde{\kappa}_\tau)H\tau$$

$$\kappa_\tau = \sqrt{\mu^{\tau\tau}}\cos(\varphi_{\tau\tau})$$

$$\tilde{\kappa}_\tau = \sqrt{\mu^{\tau\tau}}\sin(\varphi_{\tau\tau})$$



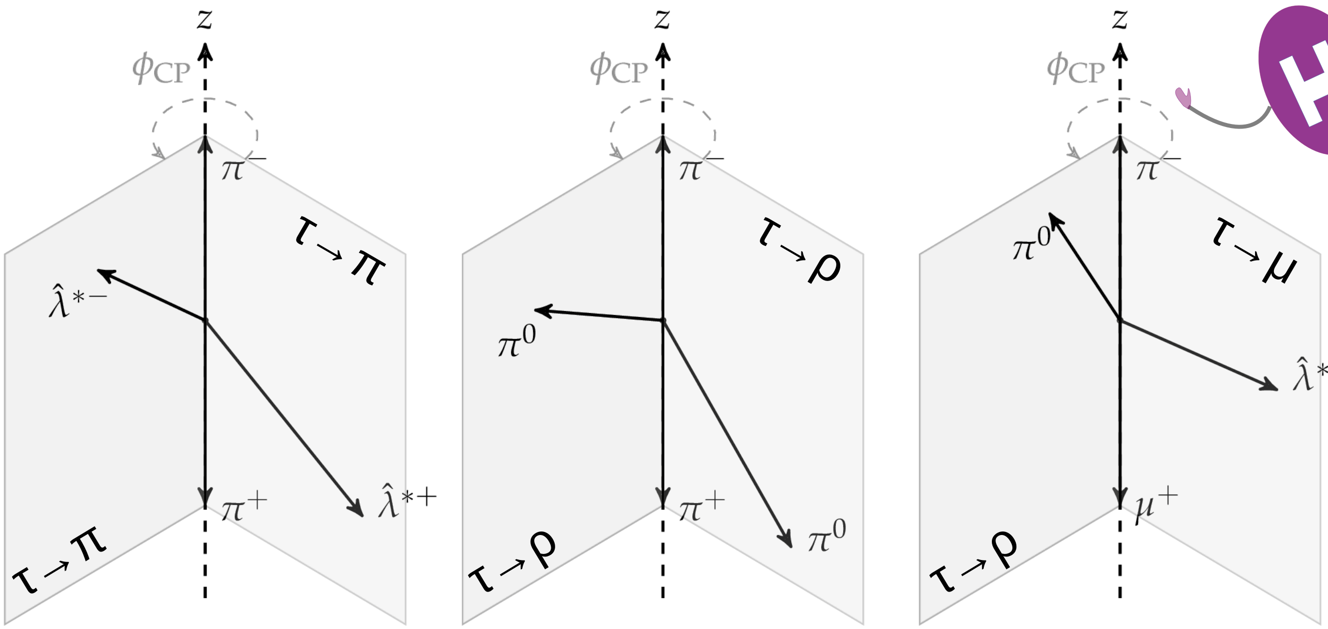
Channels studied

Investigated τ decay channels

Mode	$\mu^\pm$	$\pi^\pm$	$\rho^\pm \to \pi^\pm\pi^0$	$a_1{}^\pm \to \pi^\pm\pi^0\pi^0$	$a_1{}^\pm \to \pi^\pm\pi^\mp\pi^\pm$
$\mathcal{B}(\%)$	17.4	11.5	25.9	9.5	9.8
Symbol	μ	π	ρ	a_1^{1pr}	a_1^{3pr}

Decay planes are reconstructed with the **τ decay products momenta**

Impact parameters are used if only one charged particle is present



The τ_h are identified with the **DeepTau** NN-based ID[2]

MVA-based identification of the **decay modes**[3]

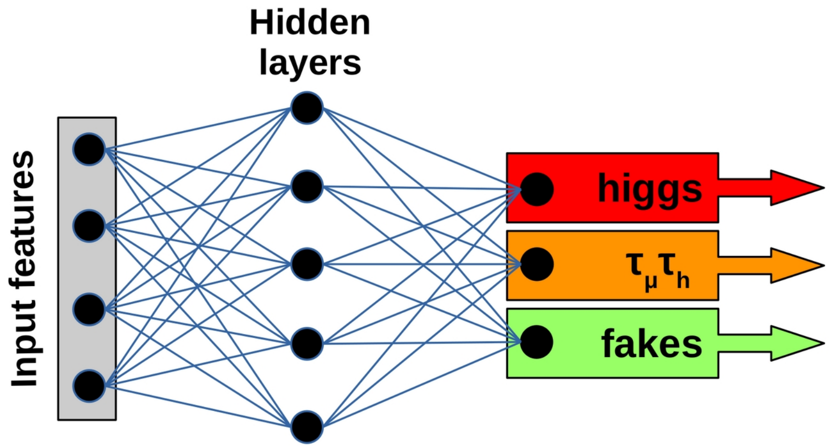
Event classification

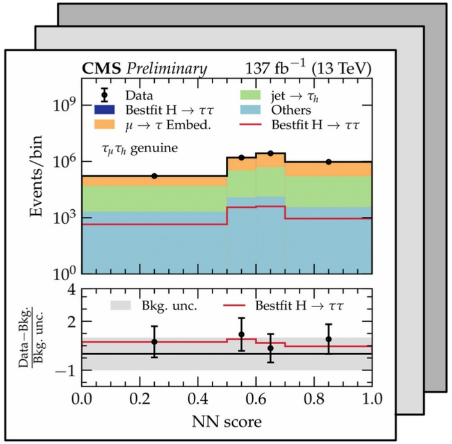
Machine learning tools[1] can be used to identify the Higgs decays from dominant backgrounds:

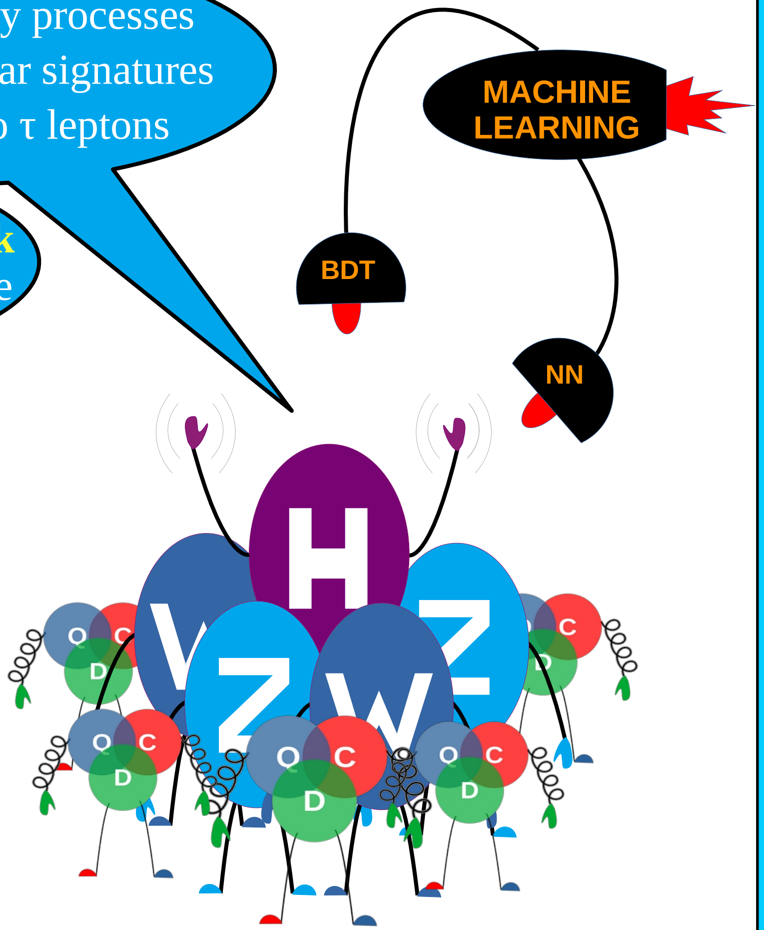
- **Genuine di-tau** production
- Lepton/jets ***faking*** τ_h

At the LHC many processes can produce similar signatures to my decays to τ leptons

BDT and **neural network** can help in identifying me



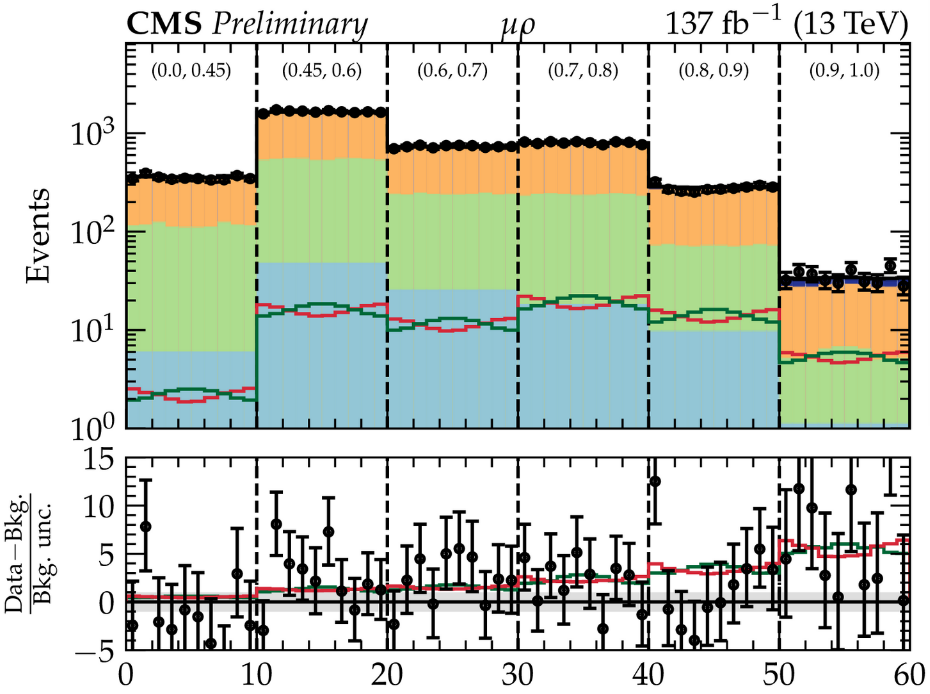




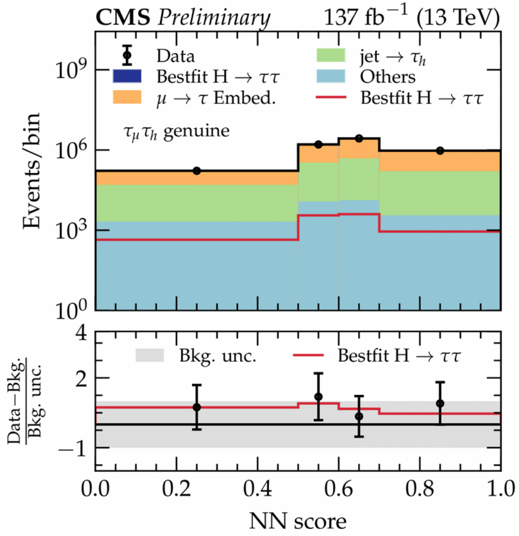
Signal extraction

Simultaneous fit of signal and background models to data for 3 years of data-taking: full Run 2

Signal category split by τ decay channel



φ_{CP} distribution in bins of NN score

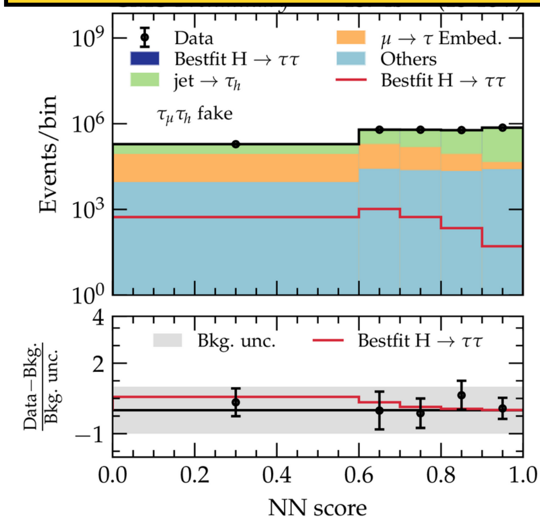


Genuine $\tau_\mu\tau_h/\tau_h\tau_h$ categories

- PS H → ττ
- Bestfit H → ττ
- Bkg. unc.

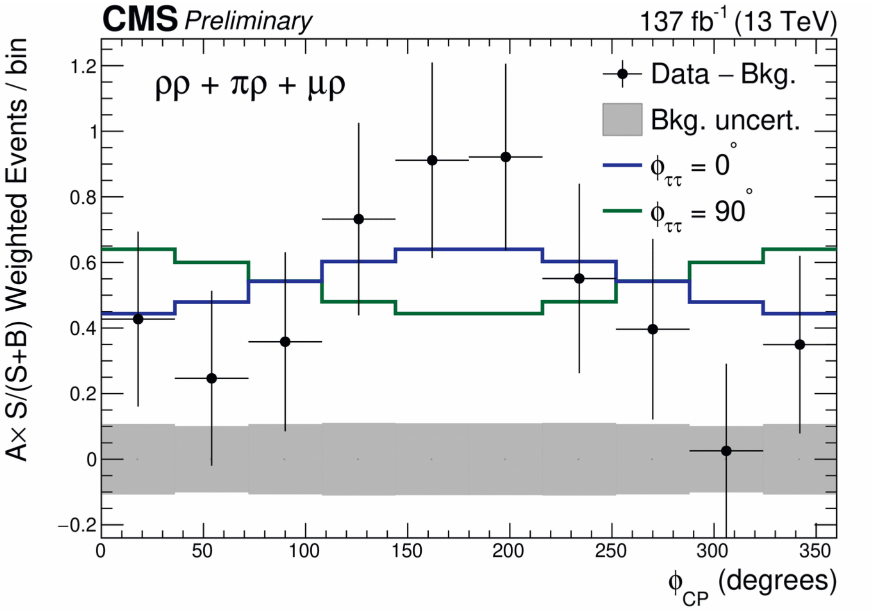
- Data
- Bestfit H → ττ
- μ → τ Embed.
- jet → τ_h
- Others
- PS H → ττ
- Bestfit H → ττ

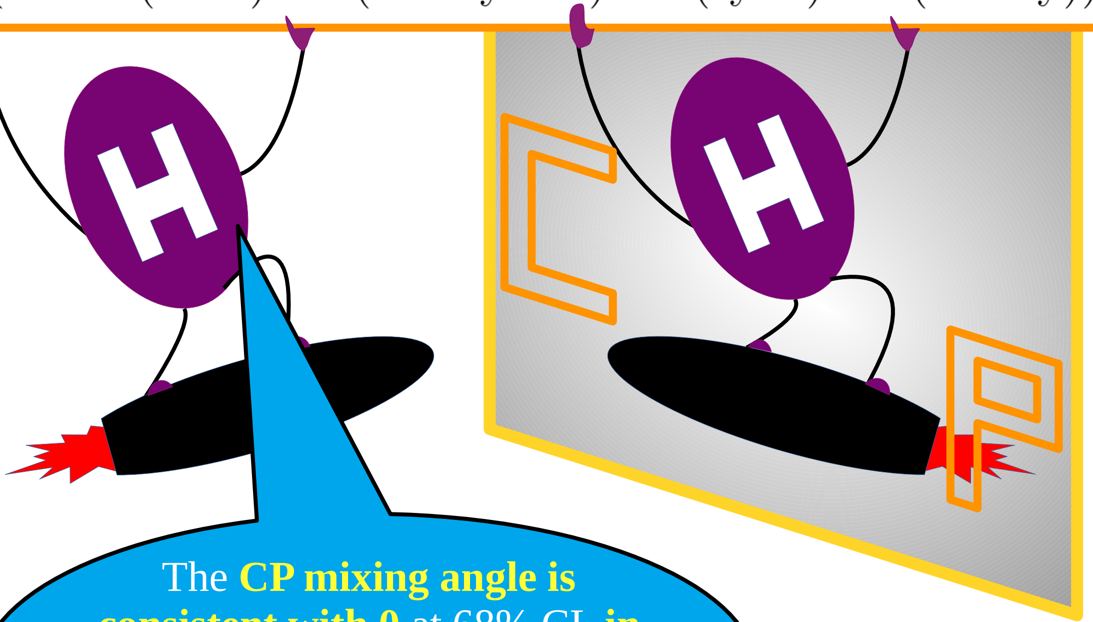
Leptons/jets faking τ_h backgrounds



Likelihood profiled[1] with respect to **CP mixing angle**

$$\varphi_{\tau\tau}^{obs} = (4 \pm 17(\text{stat.}) \pm 2(\text{bin-by-bin}) \pm 1(\text{syst.}) \pm 1(\text{theory}))^{\circ}$$





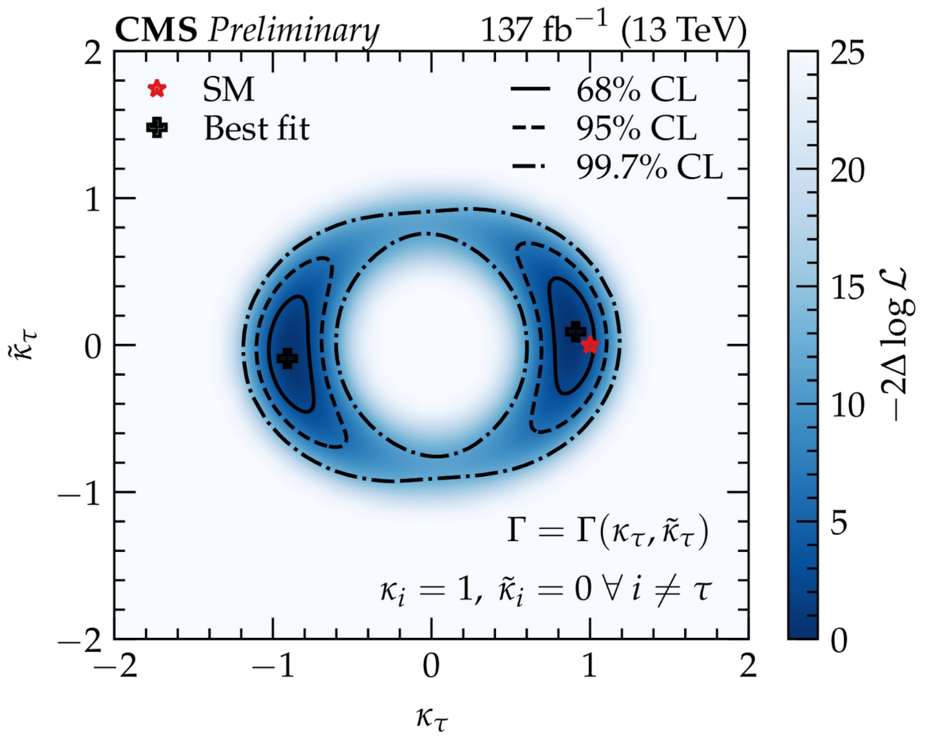
The **CP mixing angle is consistent with 0** at 68% CL **in agreement** with the **SM prediction!** A pure **CP-odd coupling** is **excluded at 99.7% CL (3.2σ)**

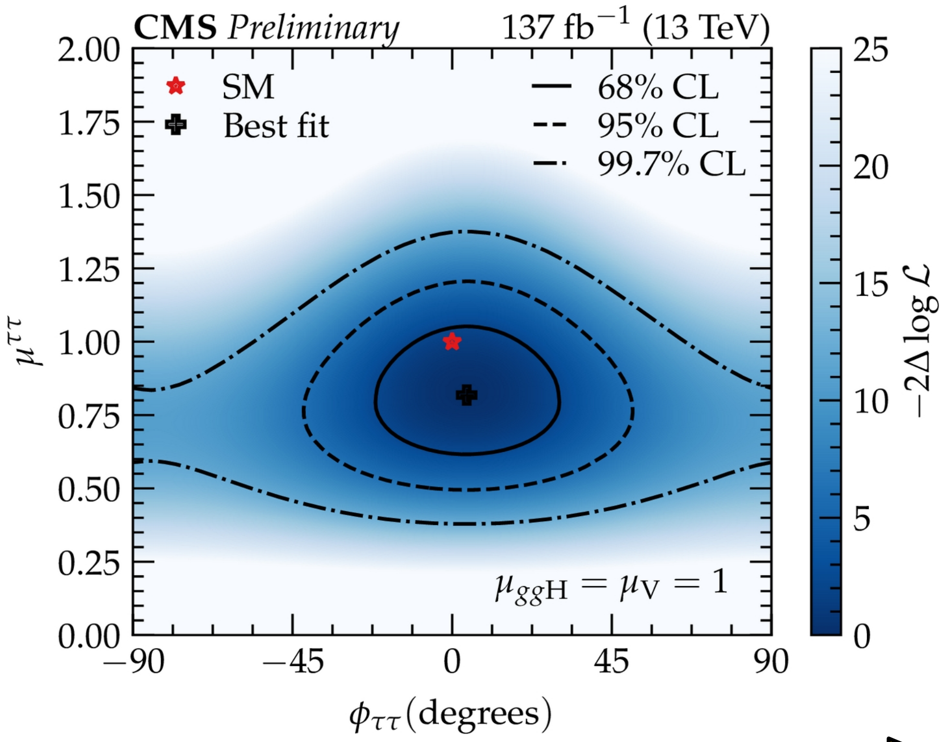
If I look at myself in the CP mirror I just see myself!

Results-part 2

Likelihood profiled[1] with respect to:

Yukawa couplings **CP mixing angle+signal strength**





Analysis **statistically** limited, to be continued in **Run 3**

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References.

1. CMS-PAS-HIG-20-006: “Analysis of the CP structure of the Yukawa coupling between the Higgs boson and τ leptons in proton-proton collisions at √s= 13 TeV”
2. CMS-DP-2019-033: “Performance of the DeepTau algorithm for the discrimination of taus against jets, electron, and muons”
3. CMS-DP-2020-041: “Identification of hadronic tau decay channels using multivariate analysis (MVA decay mode)”