



# The Higgs through the looking glass.

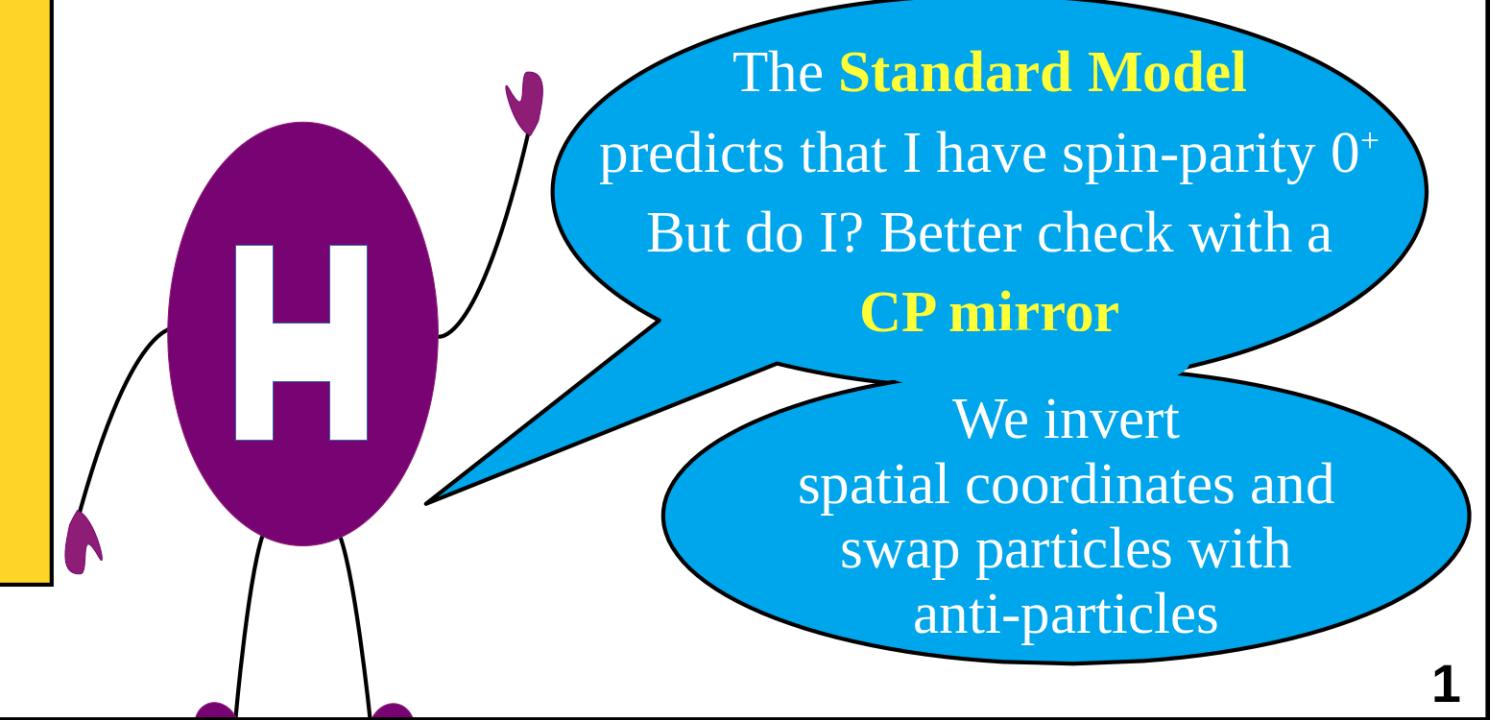
Measurement of the CP structure of the Yukawa interaction in Higgs boson decays to  $\tau$  leptons in CMS

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CP-violation in the Higgs couplings can occur in:

- HVV couplings
- Yukawa coupling:
  - Production via  $t\bar{t}H$  and  $ggH$
  - **Decays into  $\tau$  leptons**



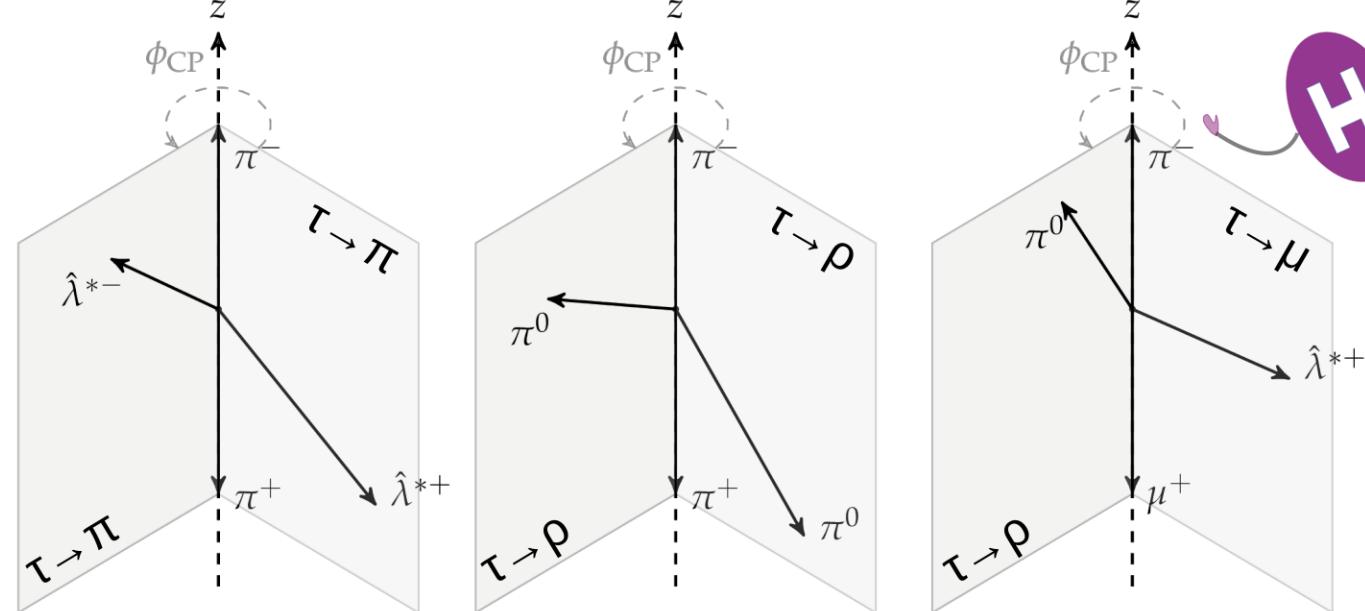
1

Investigated  $\tau$  decay channels

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

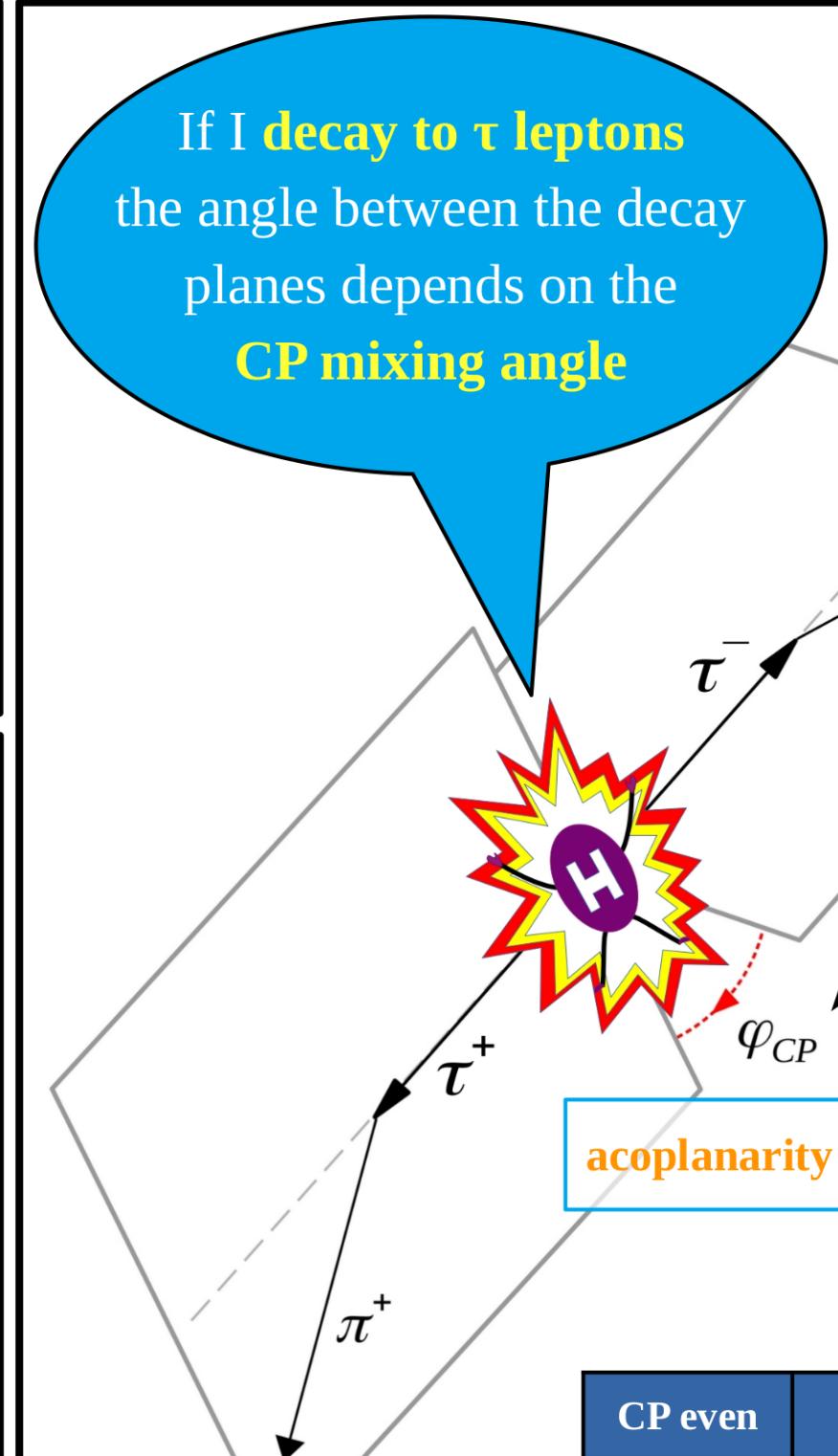
Decay planes are reconstructed with the  **$\tau$  decay products momenta**

**Impact parameters** are used if only one charged particle is present



The  $\tau_h$  are identified with the **DeepTau NN-based ID<sup>2</sup>** MVA-based identification of the **decay modes<sup>3</sup>**

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CP even	$\phi_{\tau\tau} = 0^\circ$
CP mix	$\phi_{\tau\tau} = 45^\circ$
CP odd	$\phi_{\tau\tau} = 90^\circ$

The cross-section of the  $H \rightarrow \tau\tau$  process has a **sinusoidal shape**

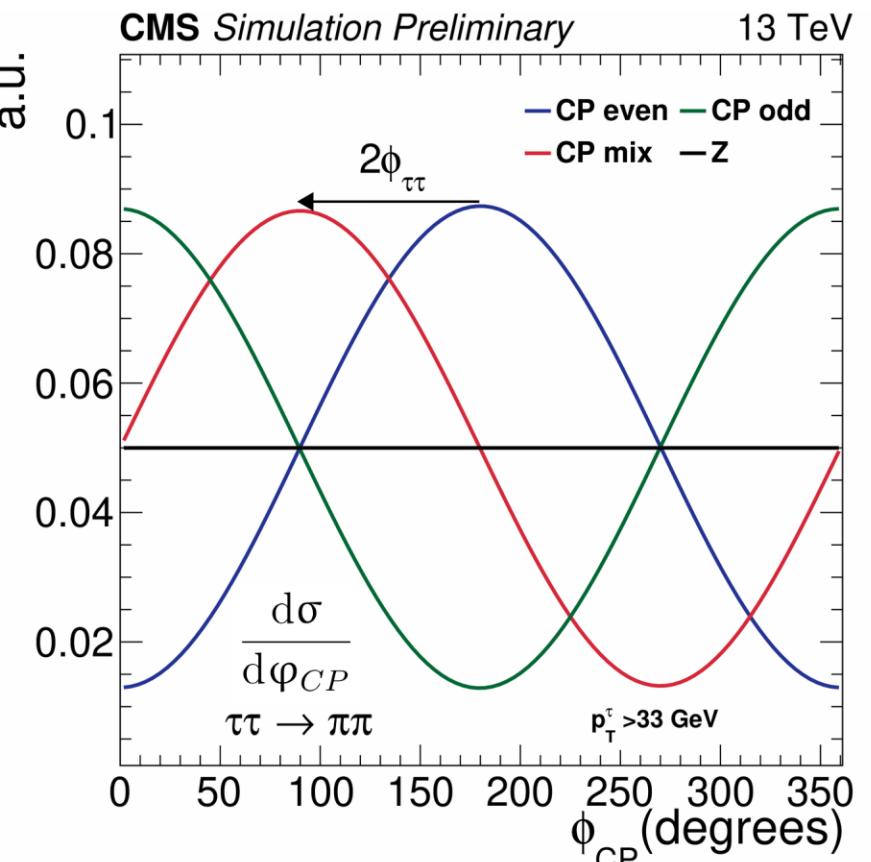
$$\frac{d\sigma}{d\phi_{CP}} \propto \text{const} - \cos(\phi_{CP} - 2\phi_{\tau\tau})$$

**CP mixing angle**

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

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

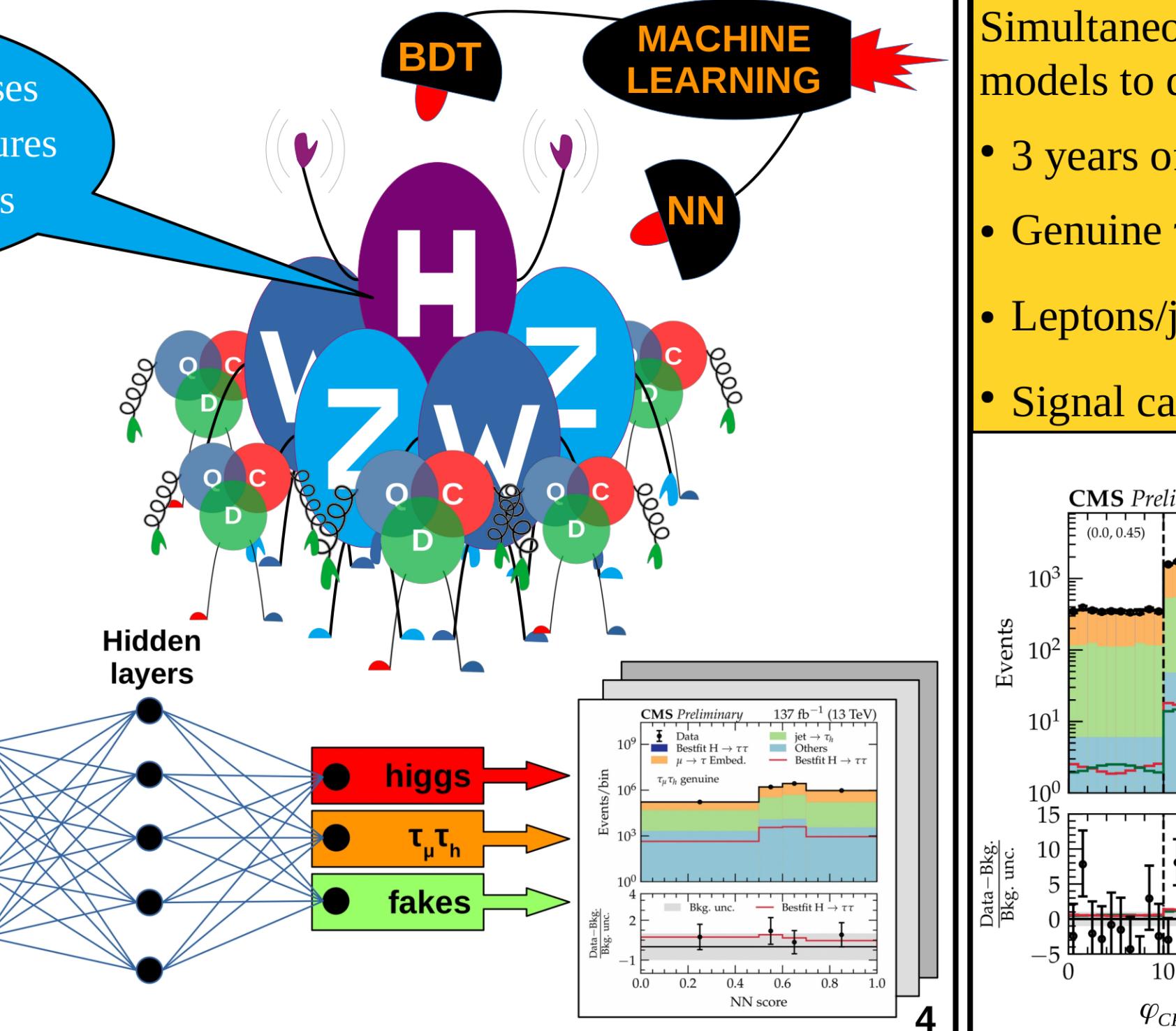
$$\tilde{\kappa}_\tau = \sqrt{\mu^{\tau\tau}} \sin(\phi_{\tau\tau})$$



2

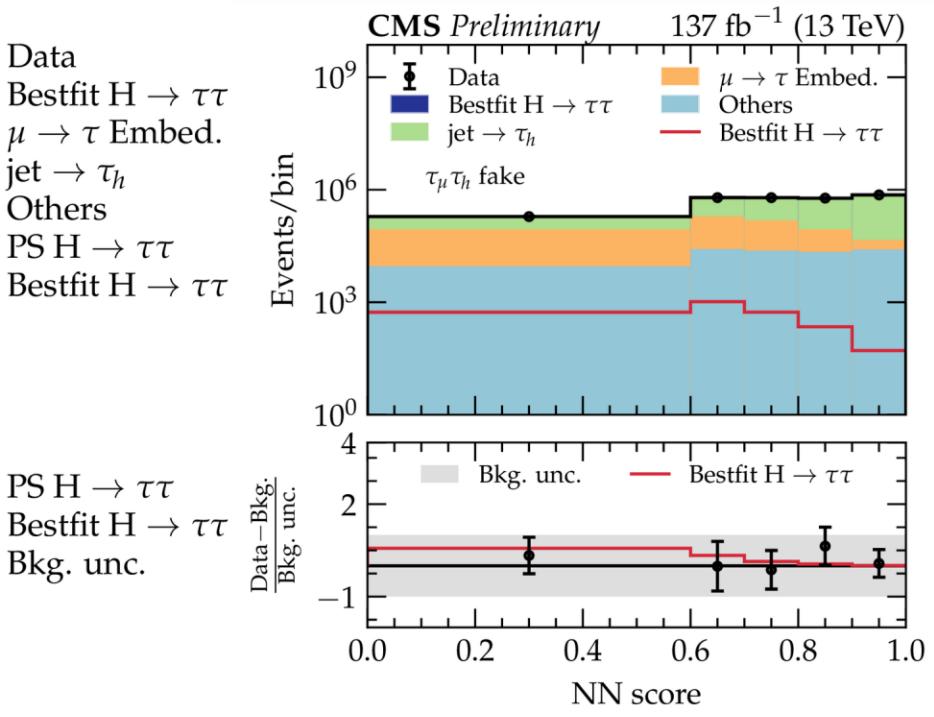
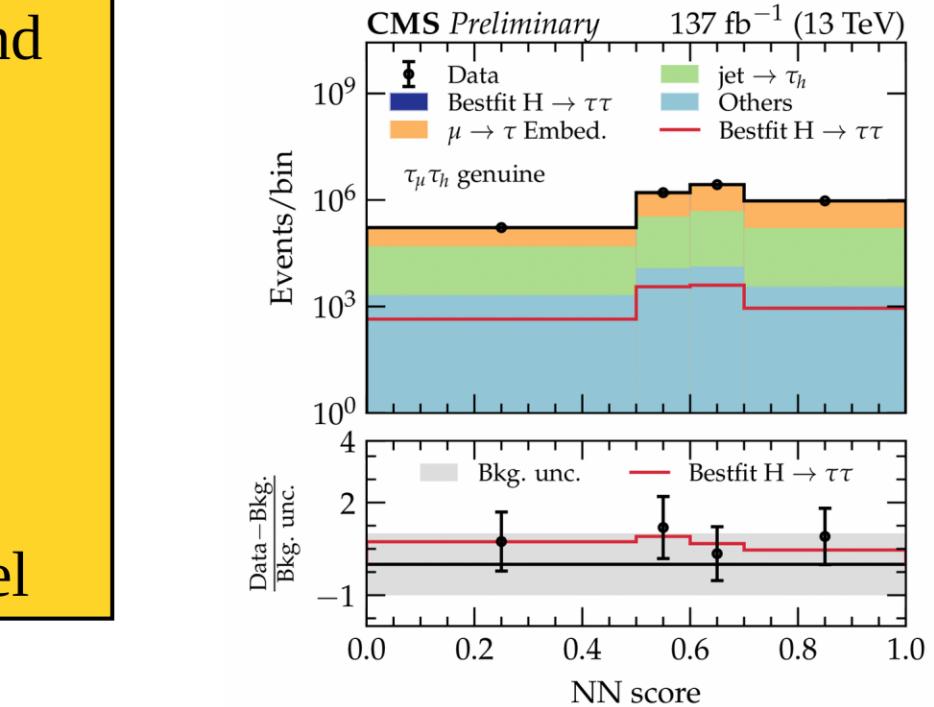
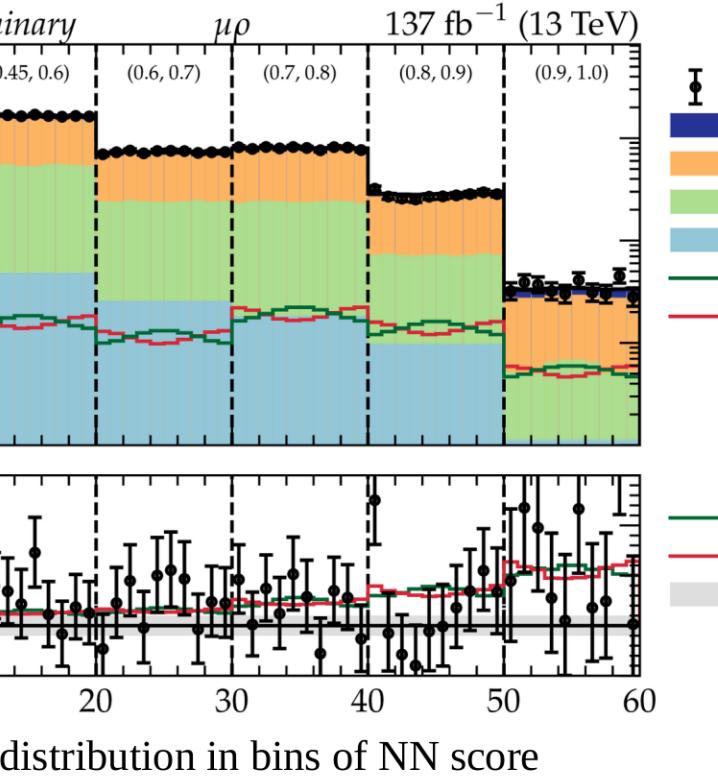
**Machine learning tools<sup>1</sup>** can be used to identify the Higgs decays from dominant backgrounds:

- **Genuine di-tau production**
- Lepton/jets **faking**  $\tau_h$



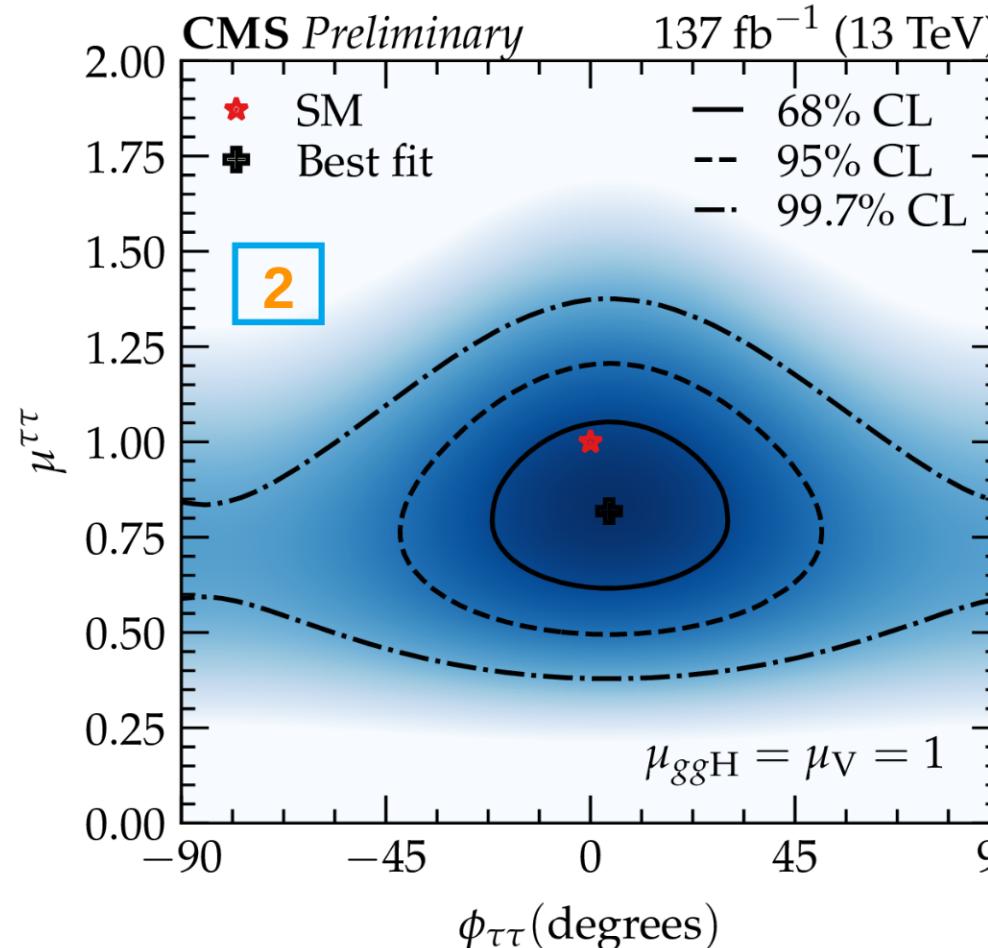
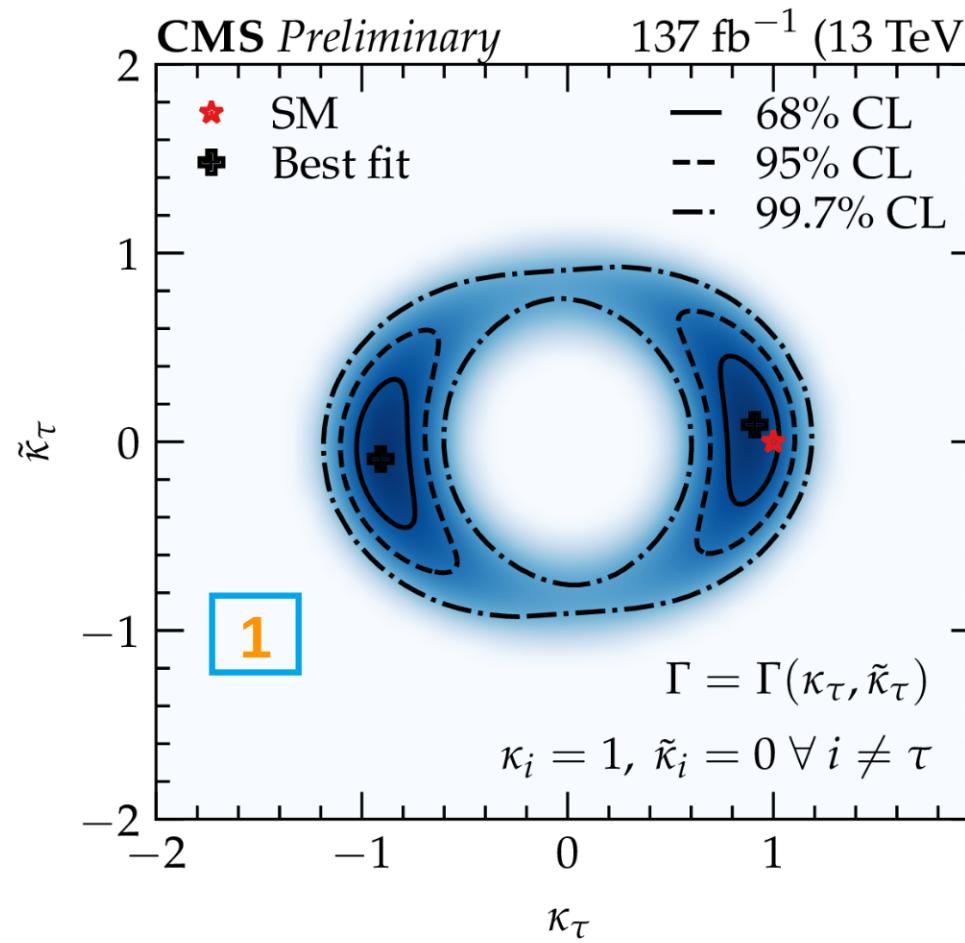
Simultaneous fit of signal and background models to data for:

- 3 years of data-taking: **full Run 2**
- Genuine  $\tau_\mu \tau_h / \tau_h \tau_h$  categories
- Leptons/jets faking  $\tau_h$  backgrounds
- Signal category split by  $\tau$  decay channel

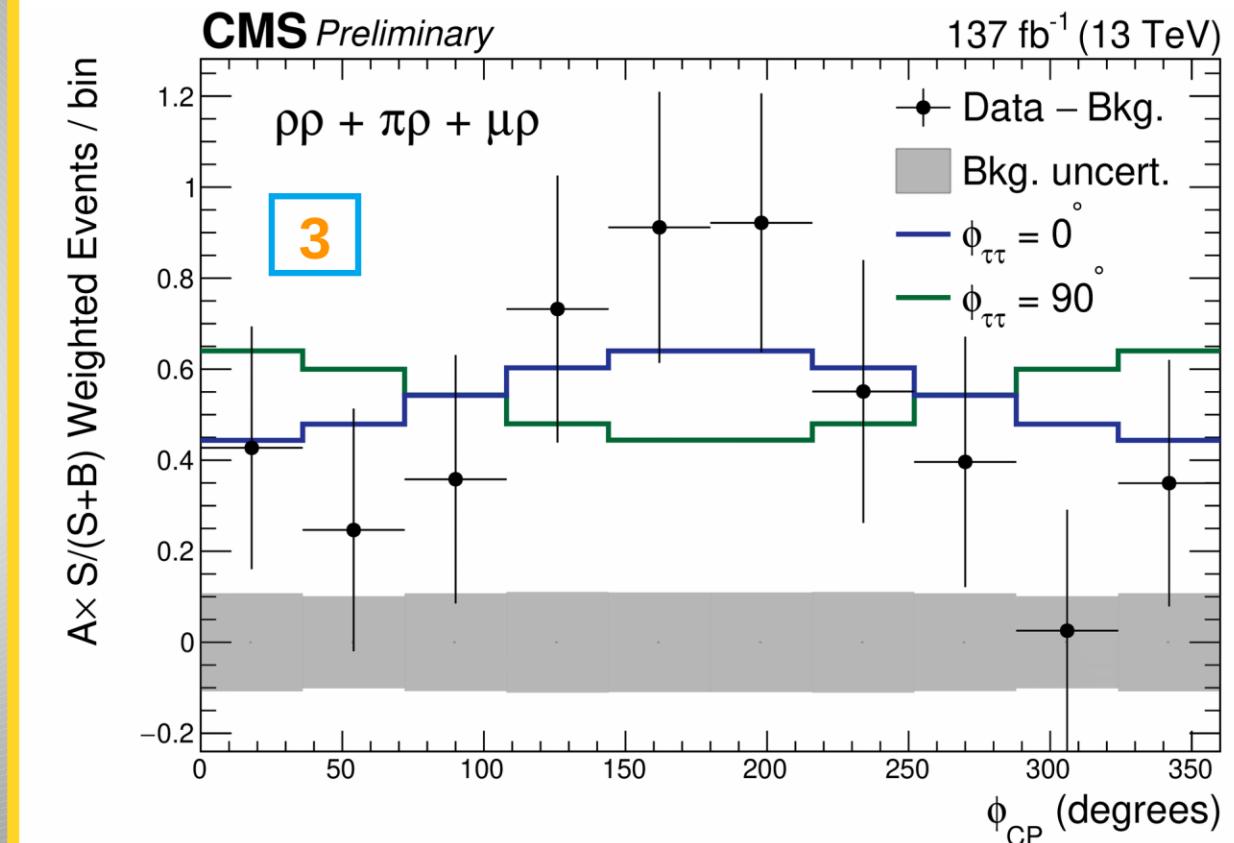
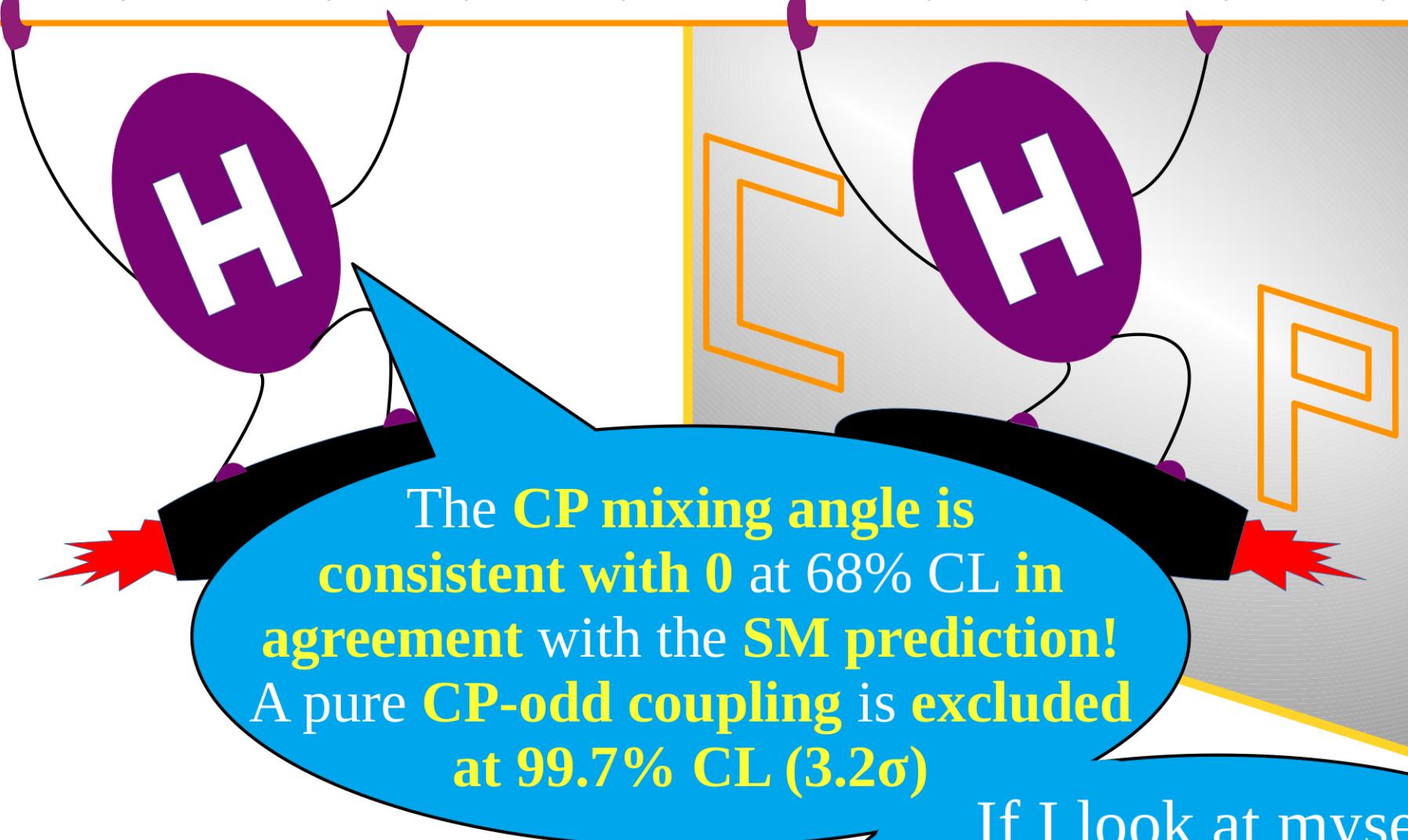


Likelihood profiled<sup>1</sup> wrt:

1. Yukawa couplings
2. CP mixing angle+signal strength
3. CP mixing angle



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



Analysis statistically limited

To be continued in Run 3

## 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  $\sqrt{s}= 13$  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)”



The Ninth Annual Conference on Large Hadron Collider Physics

# LHCP2021

7-12 June 2021 Paris (France), Sorbonne Université

