



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

The banner for LHCP2021 is at the bottom. It has a yellow and blue background. On the left, there's a silhouette of the Eiffel Tower and a sign that says "Online". In the center, "LHCP2021" is written in large blue letters, with "The Ninth Annual Conference on Large Hadron Collider Physics" below it. On the right, there's a stylized particle detector diagram. At the bottom, the dates "7-12 June 2021" and the location "Paris (France), Sorbonne Université" are listed, followed by the acronym "(IN2P3/CNRS, IRFU/CEA)".

LHCP2021
The Ninth Annual Conference on Large Hadron Collider Physics

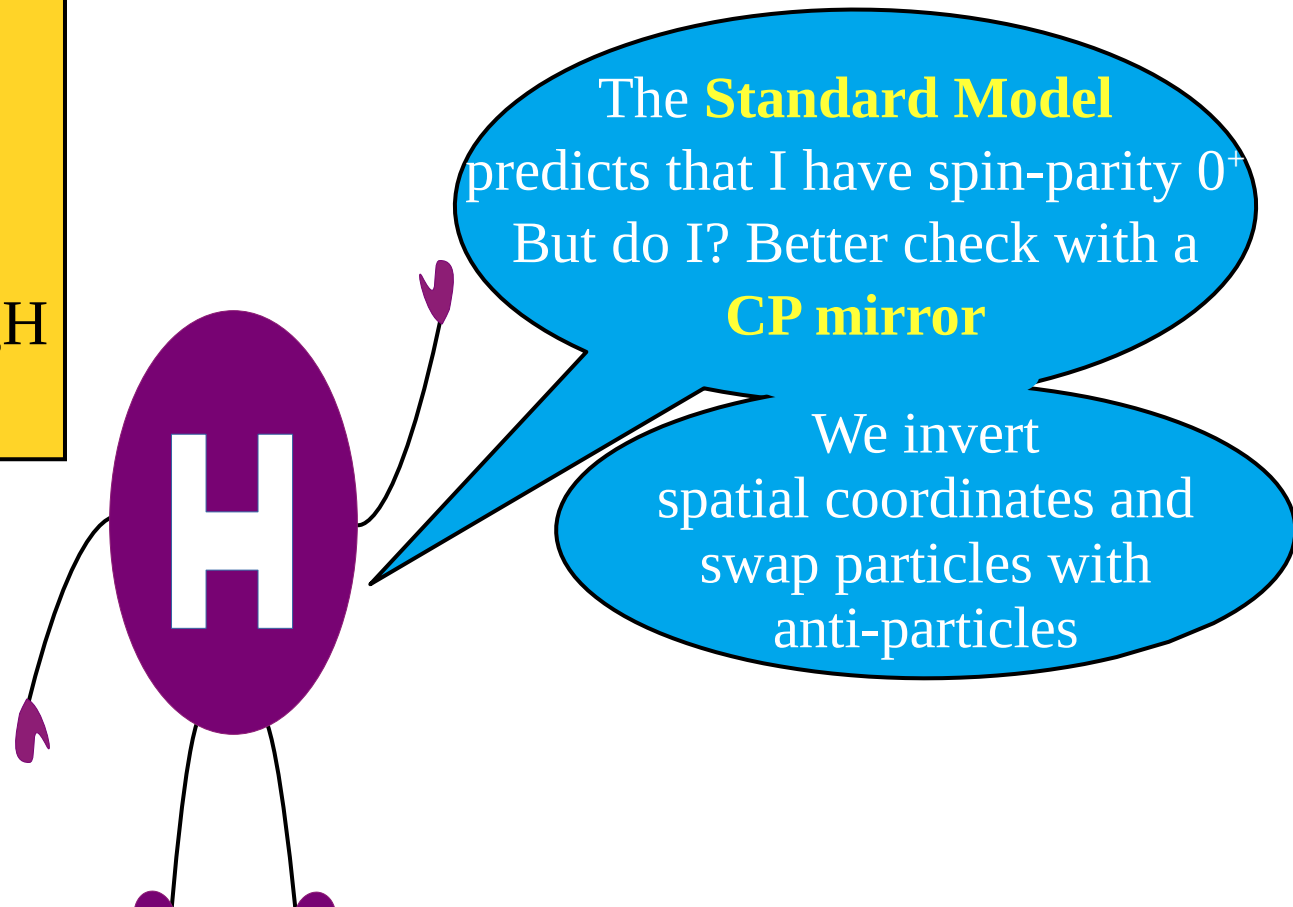
7-12 June 2021 Paris (France), Sorbonne Université (IN2P3/CNRS, IRFU/CEA)

Online

D. Longjumeau - UCLouvain 2021

CP-violation in the Higgs couplings can occur in:

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

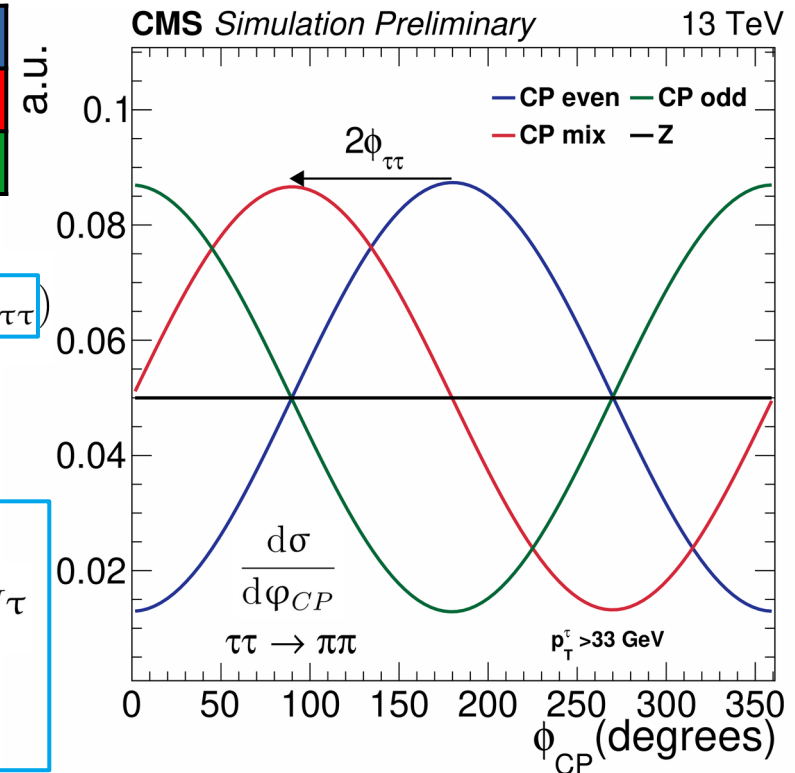


The acoplanarity angle

If I **decay to τ leptons**
the angle between the decay
planes depends on the
CP mixing angle

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

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



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

acoplanarity angle

CP mixing angle

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

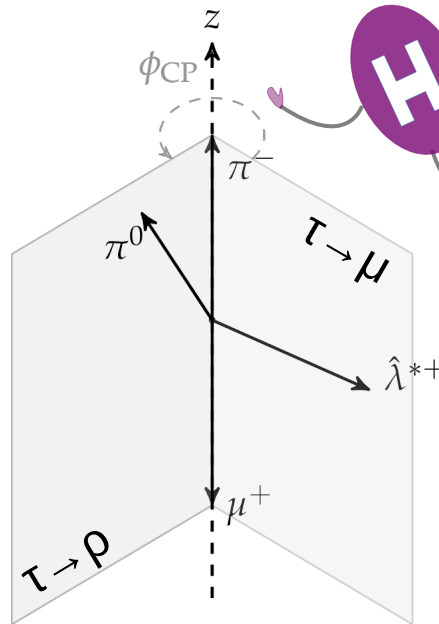
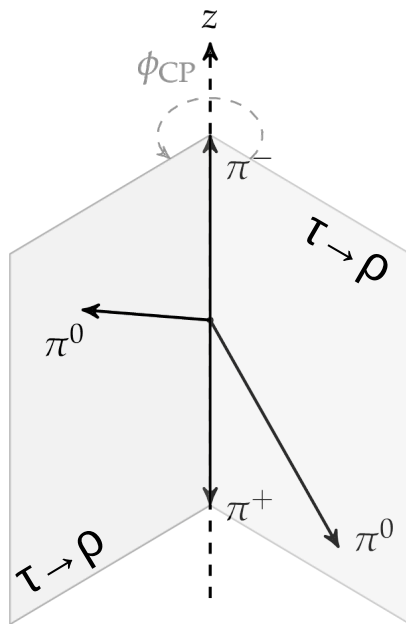
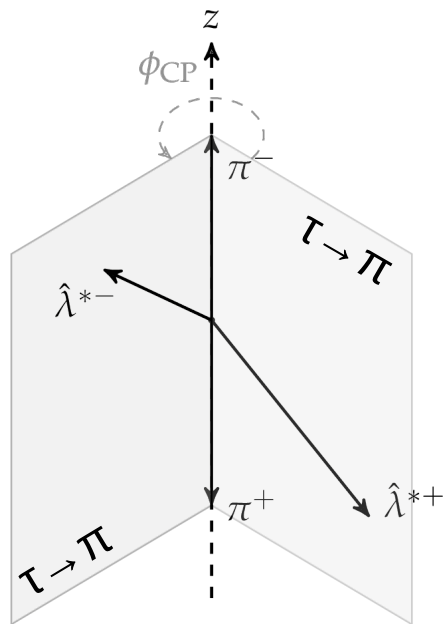
$$\kappa_\tau = \sqrt{\mu^{\tau\tau}} \cos(\varphi_{\tau\tau})$$

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

Channels studied

Investigated τ decay channels

Mode	μ^\pm	π^\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	μ	π	ρ	$a_1^{1\text{pr}}$	$a_1^{3\text{pr}}$



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 ID²
MVA-based identification of the **decay modes**³

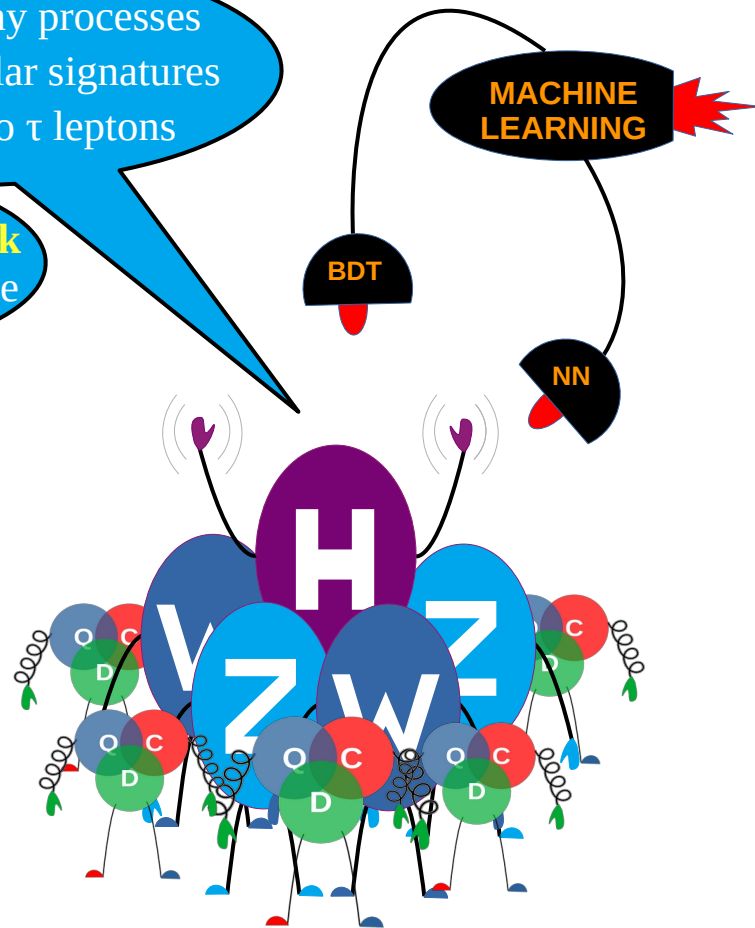
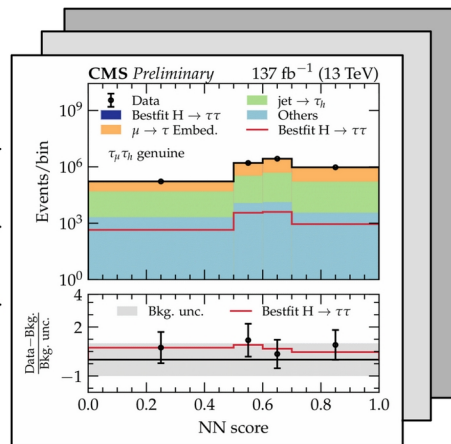
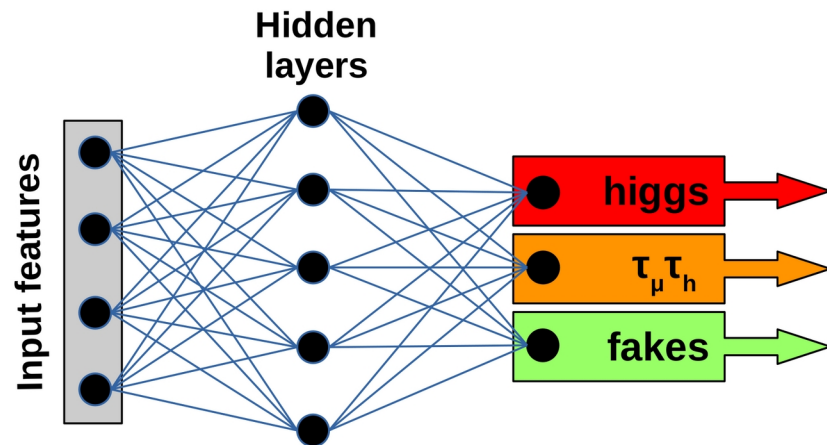
Event classification

Machine learning tools¹ can be used to identify the Higgs decays from dominant backgrounds:

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

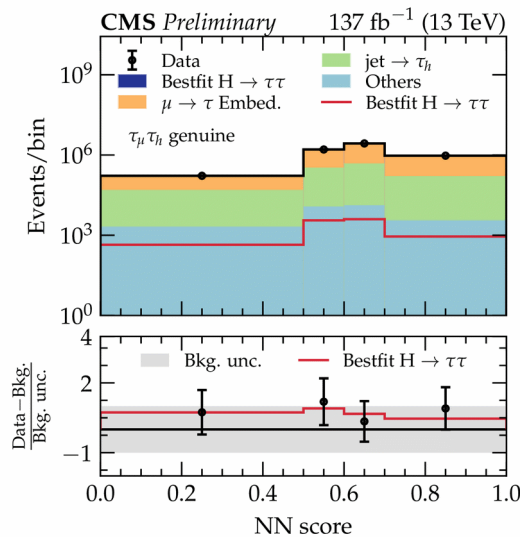
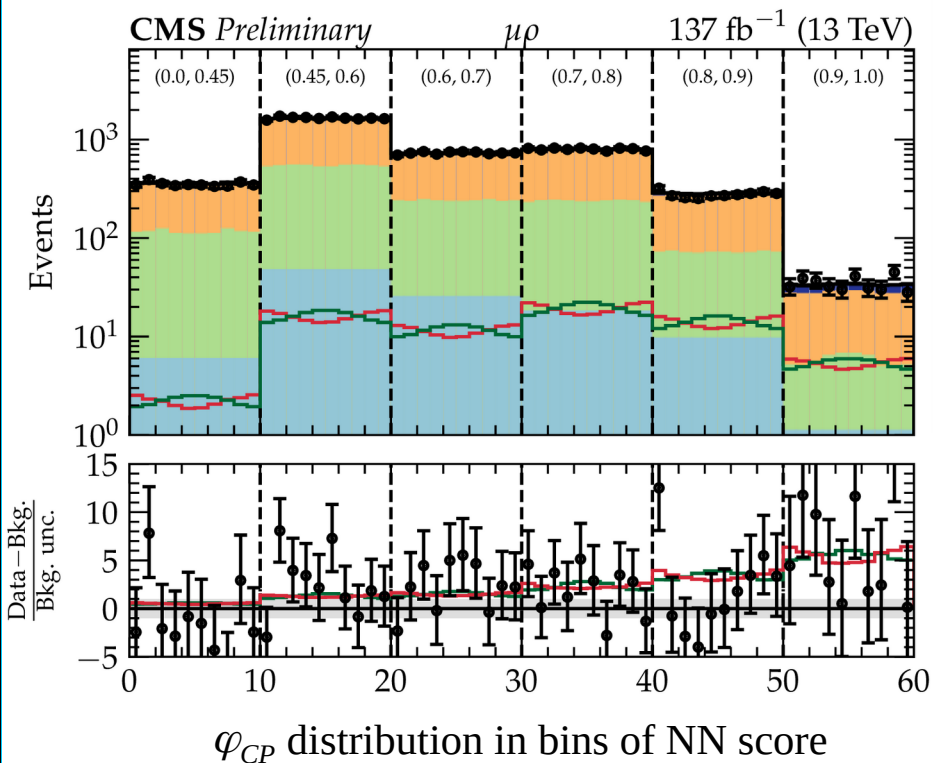
At the LHC many processes can produce similar signatures to my decays to τ leptons

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

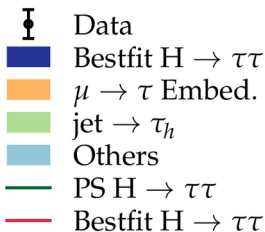
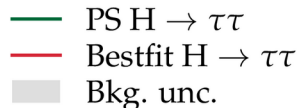


Simultaneous fit of signal and background models to data for 3 years of data-taking: **full Run 2**

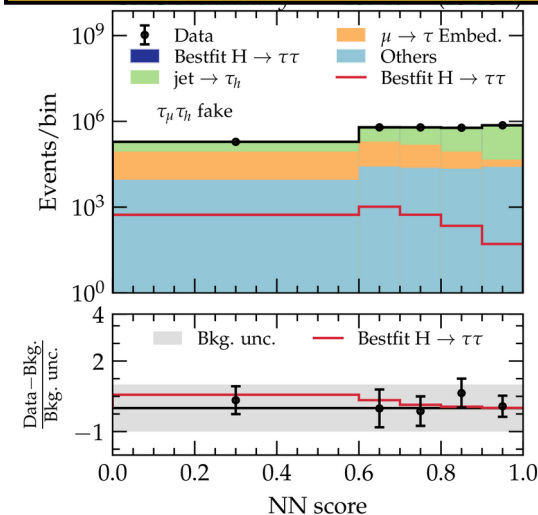
Signal category split by τ decay channel



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



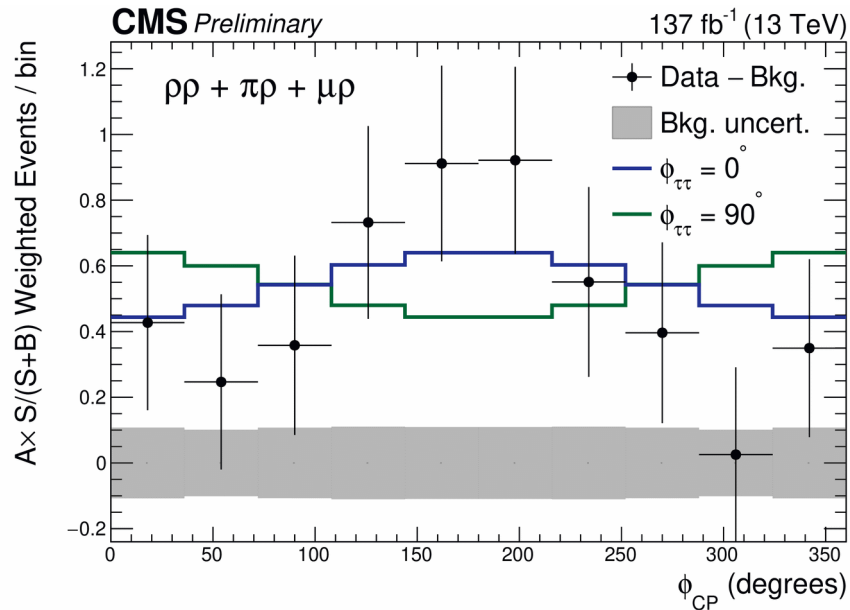
Leptons/jets faking τ_h backgrounds



Results-part 1

Likelihood profiled¹ with respect to **CP mixing angle**

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



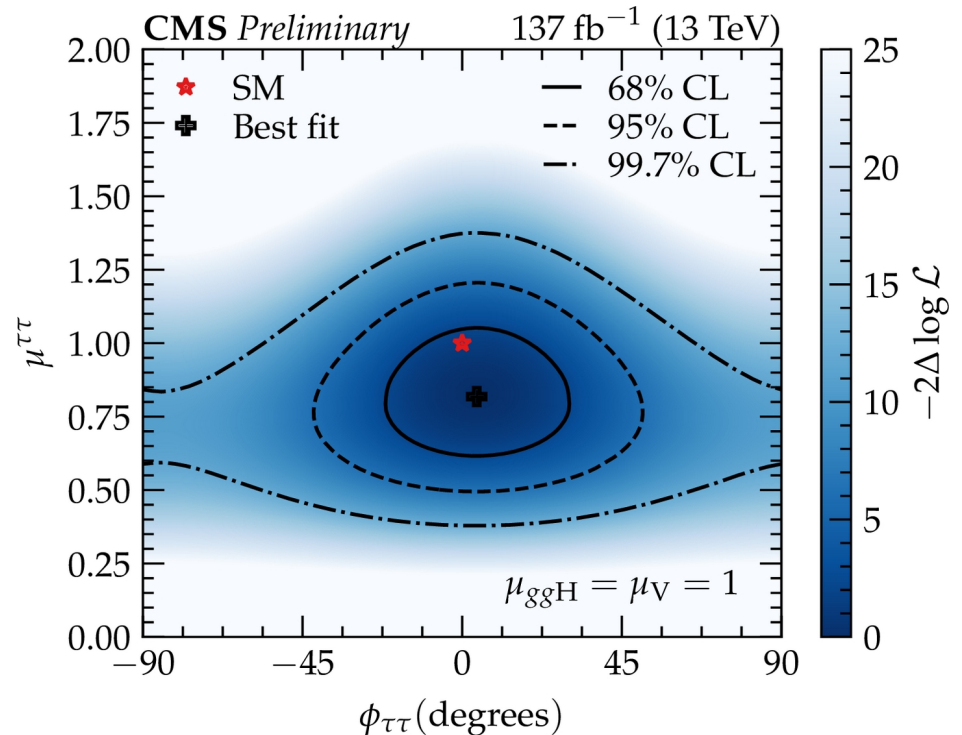
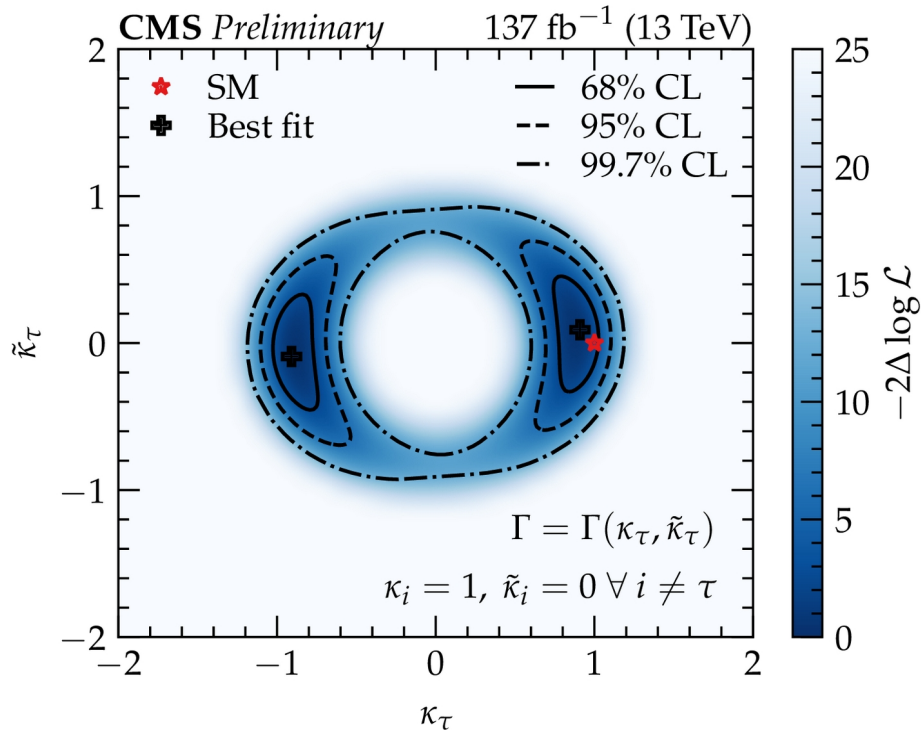
The **CP mixing angle** is
consistent with 0 at 68% CL in
agreement with the **SM prediction!**
 A pure **CP-odd coupling** is excluded
at 99.7% CL (3.2 σ)

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

Likelihood profiled¹ 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 $\sqrt{s}=13$ 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)”

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