Measurement of the CP properties of the Higgs boson in the decay into tau leptons with the Run 3 data of the CMS experiment

DPG Spring Meeting 2024

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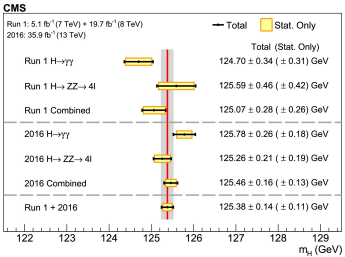
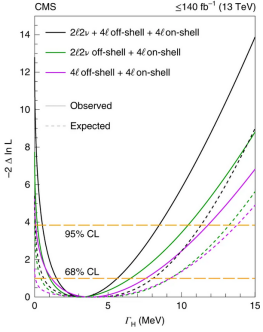
Standard model Higgs boson



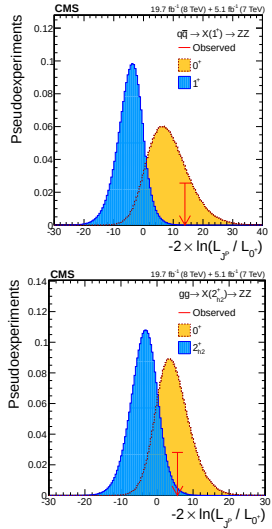
Phys. Lett. B 805 (2020) 135425

$$m_{\mathrm{H}} = 125.38 \pm 0.14 \pm 0.11 \text{ GeV}$$



Nat. Phys. 18 (2022) 1329

$$\Gamma_{\mathrm{H}} = 3.2^{+2.4}_{-1.7} \text{ MeV}$$

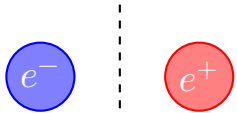


Phys. Rev. D 92 (2015) 012004

Various Higgs J^{PC} models were tested

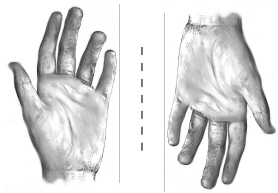
Recap: C and P transformations

C–parity



- Replaces wave function of a particle to a wave function of the antiparticle
- $\hat{C}\ \psi(e^-) = \psi(e^+)$
- Conserved by strong and electromagnetic interactions

P–inversion



- Performs "mirror reflection" of particle's coordinates
- $\hat{P}\ \psi(e^-[\vec{r}]) = \psi(e^-[-\vec{r}])$
- Also conserved by strong and electromagnetic interactions

Standard model Higgs boson CP parity

> SM Higgs boson is **CP-even**

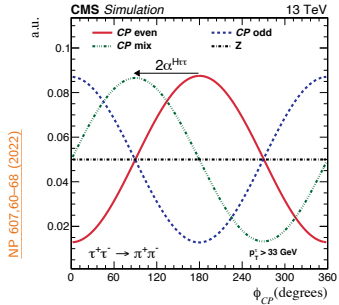
How to measure CP parity???

> Take a look at Lagrangian:
> $\mathcal{L}_Y = \frac{m_\tau}{\mu}(\kappa_\tau \bar{\tau}\tau + \tilde{\kappa}_\tau \bar{\tau} i\gamma_5 \tau)H$

> Let us define: $\arctan\left[\frac{\tilde{\kappa}_\tau}{\kappa_\tau}\right]$ as $\alpha^{H\tau\tau}$

> $$\frac{d\Gamma}{d\phi_{CP}} \sim 1 - \frac{\pi^2}{16} b(E^+) b(E^-) \cos[\phi_{CP} - 2\alpha^{H\tau\tau}]$$

> By examining distribution of ϕ_{CP} one can determine Higgs CP parity



NP 607,60–68 (2022)

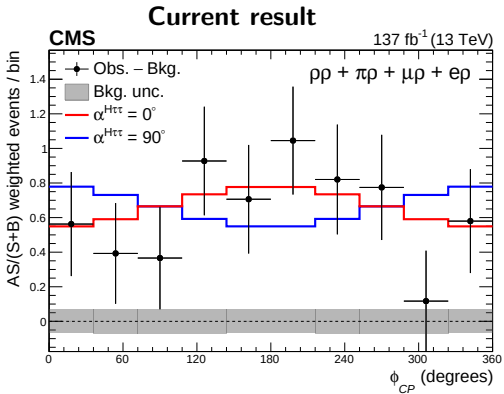
JHEP06(2022)012

H$\to \tau\tau$: current status

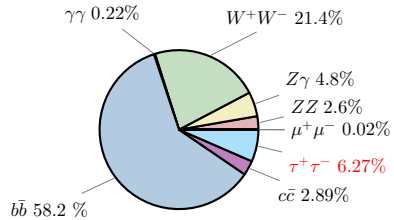
CMS Run2 result is: $\alpha^{H\tau\tau} = -1 \pm 19(\text{stat.}) \pm 1(\text{syst.}) \pm 2(\text{bin-by-bin}) \pm 1(\text{theo.})^\circ$ @ 68.3% CL

- This result has a statistically-dominated uncertainty
- $\leq 7^\circ$ uncertainty on $\alpha^{H\tau\tau}$ required to probe BSM scenarios
- Run3 campaign will double the statistics
- We expect statistical uncertainty for Run2 + Run3 to reduce by 40%

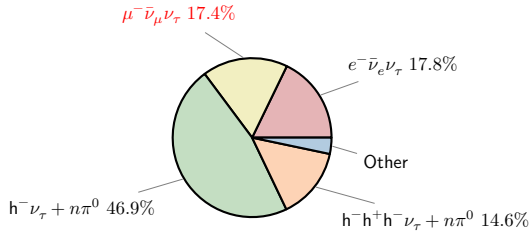
JHEP06(2022)012



Run2 H→ $\tau\tau$ CP analysis pipeline



Higgs boson decay channels



Tau lepton decay modes

Object reconstruction

- Particles
- Event properties
- Polarimetric variables

→ **Applying corrections***

Selection & reconstruction

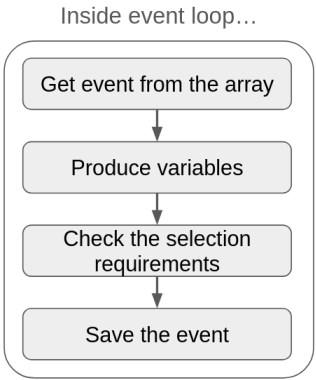
- Selecting e, μ, τ_h
- Reconstructing Higgs candidates
- Applying vetoes

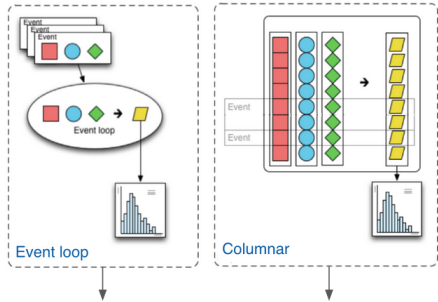
Measurement itself

- Background estimation
- Introducing systematic uncertainties
- Performing a fit of ϕ_{CP}

*Some of the corrections are applied on the Selection & reconstruction step

Columnar analysis approach

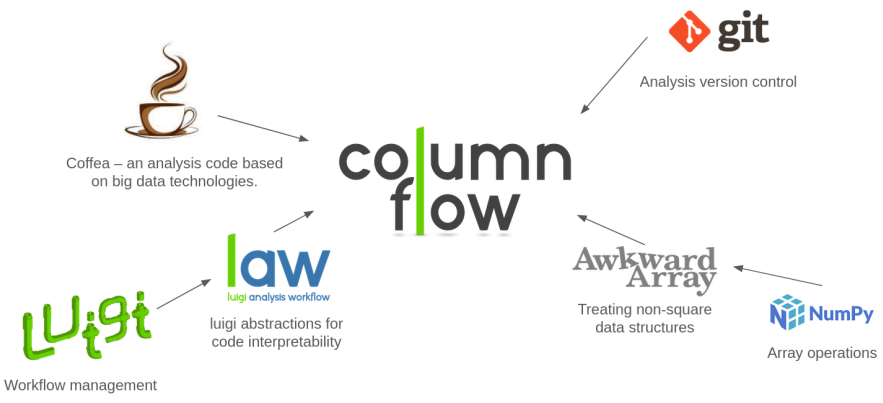




- Explicit ‘for’ loops
- Loads all variables
- High Memory load

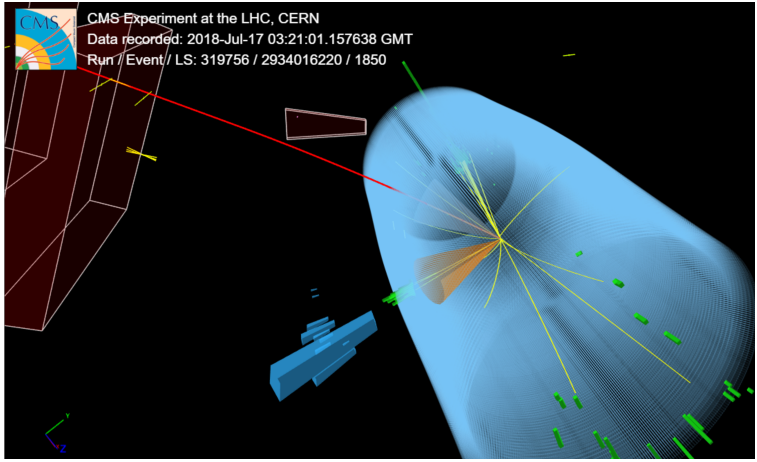
- Implicit loops
- Loads variables needed
- Resource-Friendly Code

Using Columnflow for analysis orchestration

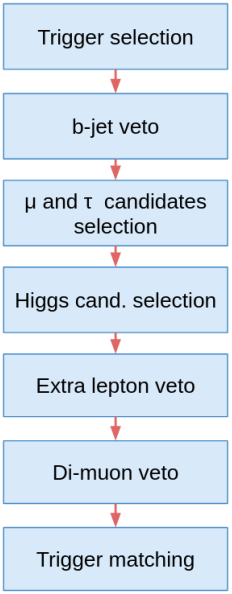


Columnflow task graph

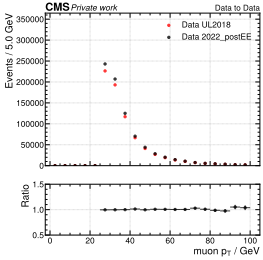
Object selection

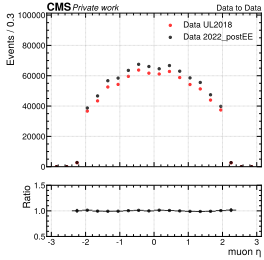


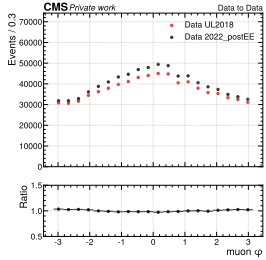
JHEP 06 (2022) 012

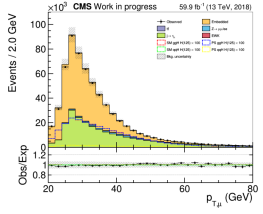


Muon kinematics: data to data comparison









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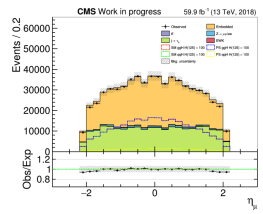

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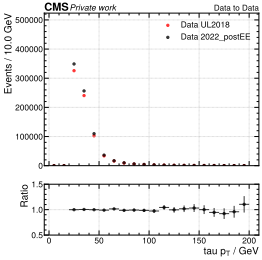
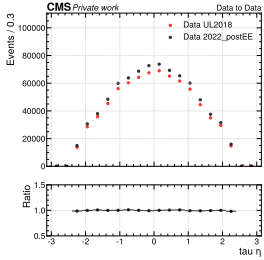
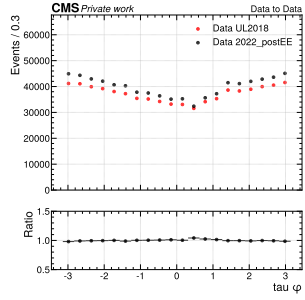
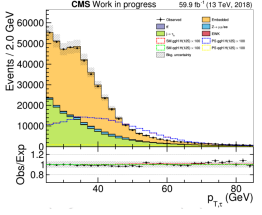
- It took a few hours to process 4 data-taking periods within a year
- For Run2 analysis it required a few weeks!

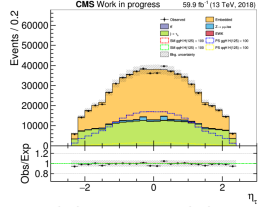
Tau kinematics: data to data comparison











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Summary

- CMS analysis of Higgs CP properties is ongoing
- It targets $H \to \tau\tau$ decays
- A new columnar approach keeps proving its efficiency
- The first results of Data to data comparison for UL2018 and 2022 postEE show a stable situation with the CMS detector

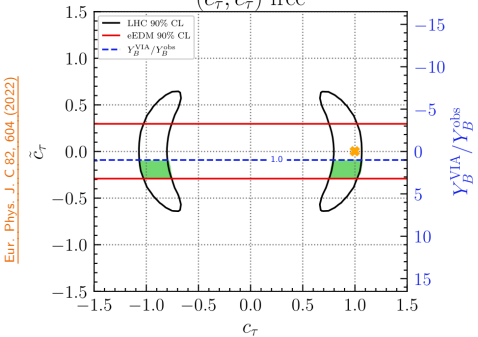
BACKUP

Requirements for the new Run3 H$\to \tau\tau$ CP analysis

- Clear and comprehensive workflow
- Possibility of combination with Run2 data
- Fast reprocessing of the analysis pipeline
- Long-term support of the code

Theoretical and experimental constraints on $H\tau\tau$ couplings

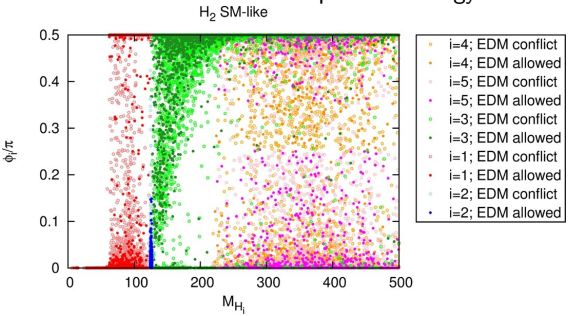
Exp.+Th. constrains
$(c_\tau, \tilde{c}_\tau)$ free



Eur. Phys. J. C 82, 604 (2022)

If uncertainty on $\alpha^{H\tau\tau} < 7^\circ$
we became sensitive to BSM

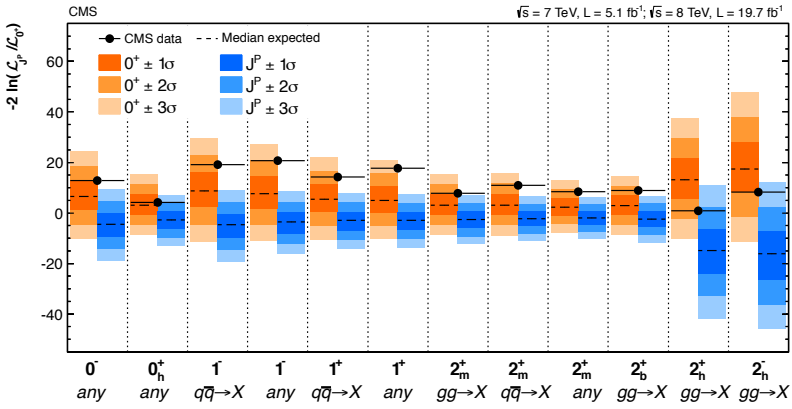
Exploring the CP-violating NMSSM:
EDM constraints and phenomenology



Nuclear Physics B Volume 901, December 2015, Pages 526-555

The phase ϕ_i, which measures the CP violation in the $H_i\tau\tau$ coupling, as a function of the mass of the Higgs boson H_i.

Spin-one and spin-two J^P models tested against the SM Higgs boson hypothesis



Phys. Rev. D 89, 092007 (2014)