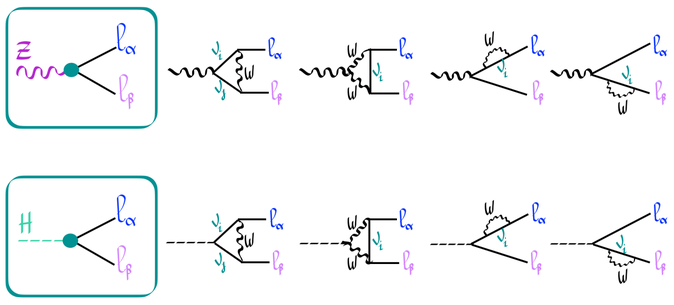
Leptonic CPV phases: impact for Higgs & Z decays and CP-asymmetries

Emanuelle Pinsard - Laboratoire de Physique de Clermont

HNL & boson decays

Contribution of the **heavy neutral leptons** (HNL) & their **CPV phases** to cLFV boson decays:

$Z \to \ell_\alpha \ell_\beta$ and $H \to \ell_\alpha \ell_\beta$



A. Abada, J.Kriewald, EP, S. Rosauro, A. M. Teixeira, arXiv:2207.10109

Minimal $3+2\,\nu_s$ for phenomenological analyses

↝ Ad-hoc construction: SM + 2 **Majorana massive** states

⇒ **new mixings** and **CPV phases** (Dirac & Majorana)

↝ No assumption on the **mass generation mechanism**

↝ **Well-defined interactions** in the physical basis

⟹ Explore the **low-energy phenomenology** common to complete models (type I seesaw, ISS, ...)

Active-sterile mixing $\mathcal{U}_{\alpha i}$

$|n_L> = \mathcal{U}_{5\times5}\,|\nu_i>$

Left-handed lepton mixing $\tilde{\mathcal{U}}_{\rm PMNS}$ 3×3 sub-block, **non-unitary**!

$$\mathcal{U}_{5\times5} = \begin{pmatrix} \mathcal{U}_{e1} & \mathcal{U}_{e2} & \mathcal{U}_{e3} & \mathcal{U}_{e4} & \mathcal{U}_{e5} \\ \mathcal{U}_{\mu1} & \mathcal{U}_{\mu2} & \mathcal{U}_{\mu3} & \mathcal{U}_{\mu4} & \mathcal{U}_{\mu5} \\ \mathcal{U}_{\tau1} & \mathcal{U}_{\tau2} & \mathcal{U}_{\tau3} & \mathcal{U}_{\tau4} & \mathcal{U}_{\tau5} \\ \mathcal{U}_{s1} & \mathcal{U}_{s2} & \mathcal{U}_{s3} & \mathcal{U}_{s4} & \mathcal{U}_{s5} \\ \mathcal{U}_{s'1} & \mathcal{U}_{s'2} & \mathcal{U}_{s'3} & \mathcal{U}_{s'4} & \mathcal{U}_{s'5} \end{pmatrix}$$

⇒ **Modified** charged & **neutral lepton currents**!

↝ **Sizeable contributions** to **cLFV observables**

↝ **Interference effects** between heavier states expected

Constructive & **destructive interference effects in** cLFV leptonic & boson decays!

Phenomenological study

All available experimental constraints are included

✓ Limits on **active-sterile mixings**

✓ Negative results of **searches for sterile states**

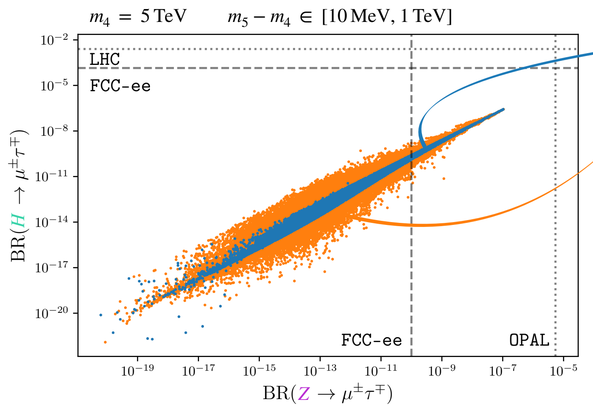
✓ **Electroweak precision** tests

✓ Bounds on other **cLFV transitions**

⟹ **No assumptions** on the **active-sterile mixings** & **random variation** of all new **CPV phases**

CPV phases & cLFV boson decays

Strong impact of the **sterile states** and their associated **CPV phases** on: $H \to \mu\tau$ vs. $Z \to \mu\tau$



Strong correlation (CP conserving)

Loss of correlation (CP violating)
Constructive & destructive interferences

CPV phases do matter!

$H \to \mu\tau$ beyond future experimental sensitivity

$Z \to \mu\tau$ within **future sensitivity** of FCC-ee

CP-asymmetries in Z decays

$Z \to \mu\tau$ decays potentially observable **AND** impacted by **CPV phases**

⟹ **Consider CP-asymmetries**

$$\mathcal{A}_{CP}(Z \to \ell_\alpha \ell_\beta) = \frac{\Gamma(Z \to \ell_\alpha^- \ell_\beta^+) - \Gamma(Z \to \ell_\alpha^+ \ell_\beta^-)}{\Gamma(Z \to \ell_\alpha^- \ell_\beta^+) + \Gamma(Z \to \ell_\alpha^+ \ell_\beta^-)}$$

Additional observables to ultimately probe the presence of CPV!

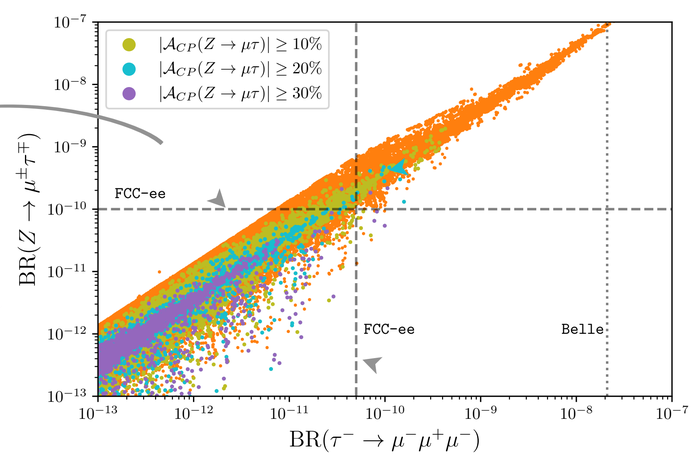
↝ Up to which extent can such a **minimal BSM** model be at the source of **non-vanishing contributions to CP-asymmetries?** (induced by *both* **Majorana** and **Dirac** **CPV phases**)

Testing HNL via several observables

Consider $\mu - \tau$ observables: $Z \to \mu\tau$, $\mathcal{A}_{CP}(Z \to \mu\tau)$ and $\tau \to 3\mu$

$Z \to \mu\tau$ within **future reach**

$\tau \to 3\mu$ within **future reach**



For $Z \to \mu\tau$ and $\tau \to 3\mu$ within future sensitivity $|\mathcal{A}_{CP}(Z \to \mu\tau)|$ can reach $\geq 20\,\%$

If **joint observation** ⟹ **highly suggestive** of such an **HNL extension**!

Impact of (potential) measurement of $\mathcal{A}_{CP}$

P_A: $m_4 = 5\,\text{TeV}, m_5 = 5.1\,\text{TeV}, s_{14} = -0.0028, s_{15} = 0.0045, s_{24} = -0.0052, s_{25} = -0.0037, s_{34} = -0.052, s_{35} = -0.028,$ $\delta_{ij} = \varphi_i = 0,$ — **CP Conserving**

P_B: $m_4 = 5\,\text{TeV}, m_5 = 5.1\,\text{TeV}, s_{14} = 0.00020, s_{15} = -7.1\times10^{-5}, s_{24} = -0.0024, s_{25} = 0.029, s_{34} = -0.073, s_{35} = -0.037,$ $\delta_{14} = 0.71, \delta_{15} = 5.21, \delta_{24} = 2.06, \delta_{25} = 4.78, \delta_{34} = 3.80, \delta_{35} = 4.74, \varphi_4 = 1.77, \varphi_5 = 4.33.$ — **CP Violating**

↝ Both benchmark points P_A and P_B lead to **common cLFV predictions:** with $\mu \to 3e$, $\mu - e$ conversion, $\tau \to 3\mu$ and $Z \to \mu\tau$ within future sensitivity

Indistinguishable mixing patterns if **only** cLFV signals are observed

BUT CP asymmetries in Z decays offer a **clear distinction**:
P_B leads to $\mathcal{A}_{CP}(Z \to \mu\tau) = 30\,\%$
⟹ **Disentangle between CP conserving** et **CPV** scenarios!

Conclusions

- **Minimal** and **simple**: SM + 2 **heavy** Majorana ν_s
- Impact of the **heavy steriles** depends on their **masses** & **mixings** with active states (**CPV**) ⇒ non unitary $\tilde{\mathcal{U}}_{\rm PMNS}$

cLFV boson decays are sensitive to the presence of **HNL**

- **CPV phases** have a **clear impact** on the decay rates
- $Z \to \mu\tau$ within future sensitivity, large associated $\mathcal{A}_{CP}$
- Importance of taking **multiple observables** into account to **distinguish** between CPV and CP conserving scenarios

CP asymmetry key to establish the presence of CPV!