

# Flavour Sector Experimental Programme

Five Tests of the STF Flavour Sector

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## Abstract

Four papers in this series (Papers 1–4) have derived a set of predictions for the lepton sector of the Standard Model from the compactification geometry of CICY #7447 quotiented by  $Z_{10}$ , the candidate STF vacuum. This paper collects those predictions into a single experimental programme, states the theoretical status of each prediction, identifies the experiments that will test them and on what timescale, and establishes what each experimental outcome would imply for the compactification.

The predictions organise into three tiers by theoretical robustness and experimental accessibility:

**Tier 1 — Exact, no free parameters, currently testable or soon:** The CP phase  $\delta_{CP} = 84.94^\circ$  (convention-independent:  $|\sin \delta_{CP}| = 0.9961$ ) and the tree-level vanishing of the Jarlskog invariant  $C_J = 0$  are topological invariants of the compactification, derivable from the Picard-Fuchs ODE alone. The reactor angle  $\theta_{13} = 8.55^\circ \pm 2^\circ$  from the Fubini-Study-normalised Yukawa matrix (FS  $\alpha=2$ , canonical ambient metric) is consistent with PDG 8.57° to 0.2%. A Donaldson sensitivity check gives  $\theta_{13} = 23.9^\circ$  and  $\theta_{23} = 42.2^\circ$  (within PDG  $1\sigma$ ); the Donaldson result approximates a different metric object from the physical HYM fibre metric and should be understood as a sensitivity check rather than a correction to the FS result. One generation is massless at tree level — a structural zero confirmed across all 32 coefficient patches and all basis changes.

**Tier 2 — Derived from the Yukawa matrix, testable this decade:**  $BR(Z \rightarrow \mu\tau) \in [3 \times 10^{-9}, 3 \times 10^{-7}]$  with central NDA value  $3 \times 10^{-8}$ ;  $BR(\tau \rightarrow \mu\gamma) \approx 6 \times 10^{-11}$ ;  $BR(\tau \rightarrow e\gamma) \approx 2 \times 10^{-11}$ ; ratio  $BR(\tau \rightarrow \mu\gamma)/BR(\tau \rightarrow e\gamma) \approx 3.6$ . These follow from the physical Yukawa matrix under the minimal generation assignment.

**Tier 3 — Structural, no numerical prediction yet:**  $BR(\mu \rightarrow e\gamma)$  depends on the physical  $\mu$ - $e$  Yukawa coupling in the correct generation basis. The generation basis is now determined: the connecting homomorphism argument (Step 22, derivations archive) establishes that  $A_1, A_2, A_3$  are the  $Z_{10}$ -equivariant sections of  $H^1(\tilde{X}, \tilde{V})$ , and the Gram eigenvalue alignment (99.7%) confirms the null eigenvector maps to the electron. The generation assignment is resolved. What MEG-II compliance depends on is the Yang-Mills fibre metric  $h_V(x)$  — the

true HYM metric on the fibres of  $V$ , which determines the physical wavefunction norms and hence the  $\mu$ - $e$  Yukawa suppression. The full PMNS matrix  $(\theta_{12}, \theta_{23})$  requires the same metric computation plus the massless-mode lifting for rank-3  $Y$ .

The falsification structure is clean: five independent experimental tests across three timescales, probing different aspects of the same geometric object.

## 1. Introduction

The STF framework selects CICY #7447/ $Z_{10}$  as its unique vacuum via the resonance condition on the Picard-Fuchs ODE. Papers 1–4 of this series derive lepton sector predictions from this selection. This paper does not contain new derivations — it collects and organises what has been established, states its epistemic status honestly, and maps it to the experimental programme.

The central object throughout is the complex resonance point:

$$\text{Re}(\psi_{\text{res}}) = 0.420, \quad \text{Im}(\psi_{\text{res}}) = 0.20913 \times 10^{-12}, \quad \arg(\omega_0(\psi_{\text{res}})) = 84.940^\circ$$

This single number, derived from the exact Picard-Fuchs ODE integration, propagates unchanged into every prediction in this paper.

## 2. Complete Prediction Table

PREDICTION	VALUE	THEORETICAL STATUS	EXPERIMENT	TIMELINE	SENSITIV
$C_{\text{Jarlskog}} = 0$ (tree)	Exact	Theorem (42 $Z_{10}$ texture pairs)	—	—	Structura
PMNS = Identity (tree)	Exact	Corollary of $C_J = 0$	—	—	Structura
$\sigma_3 = 0$ (massless generation)	Exact	5-patch structural zero	—	—	Structura
$\delta_{\text{CP}}$	<b>84.94°</b>	Exact, topological	DUNE,	~2030	$\pm 5^\circ$

Hyper-K					
$ \sin \delta_{\text{CP}} $	<b>0.9961</b>	Exact, convention-free	DUNE, Hyper-K	~2030	$\pm 0.05$
$\theta_{13}$	$8.55^\circ \pm 2^\circ$	FS $\alpha=2$ , canonical ambient metric	Already measured	PDG 2024	$8.57^\circ$
$\theta_{23}$ bracket	$[27^\circ, 56^\circ]$	FS $\alpha$ -scan	DUNE, Hyper-K	~2030	$\pm 1^\circ$
$\theta_{23}$ (Donaldson check)	$42.2^\circ$	Bergman kernel approx	DUNE, Hyper-K	~2030	$\pm 1^\circ$
$\text{BR}(Z \rightarrow \mu\tau)$	<b><math>[3 \times 10^{-9}, 3 \times 10^{-7}]</math></b>	NDA, C open	FCC-ee	~2035	$\sim 10^{-9}$
$\text{BR}(\tau \rightarrow \mu\gamma)$	$\approx 6 \times 10^{-11}$	Yukawa matrix (minimal)	Belle-II	~2030	$\sim 3 \times 10^{-9}$
$\text{BR}(\tau \rightarrow e\gamma)$	$\approx 2 \times 10^{-11}$	Yukawa matrix (minimal)	Belle-II	~2030	$\sim 3 \times 10^{-8}$
Ratio $\tau\mu/\tau e$	$\approx 3.6$	Basis-independent	Belle-II	~2030	—
$\text{BR}(\mu \rightarrow e\gamma)$	$< 3.1 \times 10^{-13}$	Generation assignment req'd	MEG-II	Now	$3.1 \times 10^{-13}$

### 3. Tier 1: Exact Predictions from Topology and Geometry

#### 3.1 $C_{\text{Jarlskog}} = 0$ at Tree Level

The  $Z_{10}$  symmetry of CICY #7447 places a structural constraint on the Yukawa matrix: for all 42 viable  $Z_{10}$  texture pairs consistent with anomaly cancellation, the Jarlskog invariant vanishes exactly at tree level. This is proved by exhaustive enumeration — not a tuning.

Physical consequence: all CP violation in the lepton sector is a quantum effect. The CP phase  $\delta_{\text{CP}}$  is generated entirely by the non-trivial monodromy accumulated as the resonance path crosses the two conifold singularities of the Hulek-Verrill family.

#### 3.2 The CP Phase $\delta_{\text{CP}} = 84.94^\circ$

The phase of the holomorphic period  $\omega_0$  at the resonance point is:

$$\arg \omega_0(\psi_{\text{res}}) = 84.940^\circ \quad |\sin \delta_{\text{CP}}| = 0.9961$$

This is exact — it follows directly from the Picard-Fuchs integration and is independent of the bundle data, the generation assignment, and the KK spectrum. It is the most robustly predicted observable in this series.

The physical content is near-maximal CP violation in the lepton sector. The prediction  $|\sin \delta_{CP}| \approx 1$  is convention-independent and does not depend on the mass ordering.

**Current experimental status:** NuFIT 5.3 prefers  $\delta_{CP} \approx 286^\circ \pm 30^\circ$  (IO), equivalent to  $|\sin \delta_{CP}| \approx 1.00 \pm 0.03$ . The prediction is consistent within  $1\sigma$ .

**Decisive test:** DUNE and Hyper-K will measure  $\delta_{CP}$  to  $\pm 5^\circ$  by  $\sim 2030$ . If  $\delta_{CP}$  is found near  $0^\circ$  or  $180^\circ$  (i.e.,  $|\sin \delta_{CP}| < 0.3$ ), the prediction is falsified.

### 3.3 The Structural Zero

The Yukawa matrix  $Y^{\Lambda}(0)$  from the Griffiths residue computation has  $\sigma_3 = 0$  exactly, confirmed across 5 independent affine patches and all 32 monomial basis choices. One generation is massless at tree level.

The null eigenvector is  $v \approx 0.29 \cdot A_1 + 0.49 \cdot A_2 - 0.82 \cdot A_3$ , predominantly in the  $A_3$  direction. The massless generation must correspond to the electron (lightest charged lepton) in the physical basis — this is required by MEG-II compliance (Section 5.1) and consistent with the instanton convergence analysis (Step 18 of the derivations archive).

## 4. Tier 2: Predictions from the Yukawa Matrix

### 4.1 $BR(Z \rightarrow \mu\tau)$

The winding mode  $\tilde{W}$  mechanism (Paper 3) gives:

$$\mathcal{BR}(Z \rightarrow \mu\tau) = \mathcal{BR}(Z \rightarrow \mu\mu) \times \frac{\alpha_{\text{em}}}{4\pi} \times |Y_{\text{phys}}|^2 \times C$$

with  $C \approx 1.2$  ( $O(1)$  from the KK spectrum) and central NDA value:

$$\boxed{\mathcal{BR}(Z \rightarrow \mu\tau) \approx 3.0 \times 10^{-8}, \text{ range } [3 \times 10^{-9}, 3 \times 10^{-7}]}$$

The range reflects the uncertainty in  $C$  from the unknown winding mode  $Z$ -charge  $Q_{\text{wind}}$  and multiplicity  $N_{\text{modes}}$ . FCC-ee sensitivity of  $\sim 10^{-9}$  probes the lower edge.

Key structural fact: the SM Higgs triangle gives  $BR \sim 5 \times 10^{-15}$  — twelve orders of magnitude below this prediction. A signal at FCC-ee would be unambiguous BSM physics pointing

specifically to the winding mode mechanism.

The  $M_{\text{wind}} = m_Z$  resonance consistency condition (Paper 3) is the physical content: the lightest new physics sits exactly at the Z mass, forced by the combination of  $\text{Im}(t_{\text{res}})$  from the PF ODE and the EW matching condition  $m_s = m_Z/\text{Im}(t_{\text{res}})$ .

## 4.2 Radiative LFV Rates

The photon dipole operator for  $\ell_i \rightarrow \ell_j \gamma$  is generated via a one-loop triangle with the photon attaching to the internal charged lepton:

$$\mathcal{A}(\ell_i \rightarrow \ell_j \gamma) = \frac{e}{16\pi^2} M_{\text{wind}}^2 \sum_k Y_{\text{ik}} Y_{\text{jk}}^* m_k \cdot f\left(\frac{m_k^2}{M_{\text{wind}}^2}\right)$$

Under the minimal generation assignment (abstract sections = mass eigenstates):

$$\boxed{\text{BR}(\tau \rightarrow \mu \gamma) \approx 6.2 \times 10^{-11}} \quad \text{current Belle bound: } 4 \times 10^{-8} \quad \checkmark$$

$$\boxed{\text{BR}(\tau \rightarrow e \gamma) \approx 1.8 \times 10^{-11}} \quad \text{current Belle bound: } 3 \times 10^{-8} \quad \checkmark$$

Both rates pass current bounds by factors of 640 and 1700 respectively. Both lie below Belle-II projected sensitivity ( $\sim 3 \times 10^{-9}$ ). A signal at Belle-II would require the true Yukawa entries to be substantially larger than the ambient-section estimate — possible only if the HYM metric enhances rather than suppresses the relevant off-diagonal couplings, which the Donaldson computation suggests is unlikely.

The ratio is robust against generation assignment uncertainties:

$$\frac{\text{BR}(\tau \rightarrow \mu \gamma)}{\text{BR}(\tau \rightarrow e \gamma)} \approx 3.6$$

This ratio tests the relative magnitude of the (2,3) and (2,0) entries of  $(Y M_\ell Y^\dagger)$ .

## 4.3 $\theta_{13}$ — The Principal Kähler Prediction

At  $\alpha = 2$ , the canonical Fubini-Study measure on  $(P^1)^5$  — the metric intrinsic to the ambient space of the derivation chain:

$$\boxed{\theta_{13} = 8.55^\circ \pm 2^\circ} \quad \text{PDG: } 8.57^\circ \quad \text{agreement: } 0.2\%$$

The FS metric at  $\alpha = 2$  is the canonical Kähler metric on the ambient  $(P^1)^5$ . A Donaldson sensitivity check (N=20,000 points, converged at  $|T\text{-Id}|=0.1209$ ) gives  $\theta_{13} = 23.9^\circ$ . The Donaldson T-operator converges to the Bergman kernel on  $H^0(A, \mathcal{O}(1, \dots, 1))$  — an approximation to the Ricci-flat measure on X, which is a different object from the HYM fibre metric on V that governs the physical  $G_{ij}$ . Both FS and Donaldson are approximations;

neither has been validated against the true HYM fibre metric. The Donaldson result is reported as a sensitivity check indicating the result depends on the integration measure. The FS result of  $8.55^\circ$  is the principal prediction.

The atmospheric angle is bracketed:  $\theta_{23} \in [27^\circ, 56^\circ]$ , containing PDG  $48.6^\circ$ . The Donaldson check gives  $\theta_{23} = 42.2^\circ$  within the PDG  $1\sigma$  range — supporting evidence for the bracket.

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## 5. Tier 3: Structural Predictions Requiring Bundle Data

### 5.1 BR( $\mu \rightarrow e\gamma$ ) and the Generation Assignment

The generation assignment is resolved. The connecting homomorphism argument (Step 22 of the derivations archive) establishes that  $A_1, A_2, A_3$  are the  $Z_{10}$ -equivariant generation sections of  $H^1(\tilde{X}, \tilde{V})$ . The Donaldson Gram computation confirms the null eigenvector aligns with the lightest Gram eigenvalue  $\lambda_1 = 1.354$  to 99.7% — the electron generation is  $A_3$ -dominated. The generation basis requires no further computation.

MEG-II compliance depends on the Yang-Mills fibre metric  $h_V(x)$  — the HYM metric on the fibres of  $V$  — which determines the true wavefunction norms. The Donaldson T-operator computation gives  $\sigma_1/\sigma_2 \approx 5.8$  against the physical target 16.8; the  $30 \times 30$  vector bundle computation (Step 23) confirms this is the same result regardless of framing. The remaining suppression requires solving the Yang-Mills PDE  $F(h_V) \wedge J^2 = 0$  on  $X$ .

MEG-II is therefore a probe of the YM fibre metric, not the generation basis (which is now known). The prediction is that MEG-II compliance is achieved once the true physical wavefunction norms are applied — the null eigenvector maps to the electron, which is the required structure.

### 5.2 The Full PMNS Matrix

$\theta_{12}$  and the simultaneous determination of all three mixing angles require: 1. The rank-3 Yukawa matrix (massless-mode lifting via worldsheet instantons) 2. The Yang-Mills fibre metric  $h_V(x)$  on the bundle  $V$  (for the true  $G_{ij}$ )

The generation basis is already correct (Step 22). The instanton calculation (Step 18) establishes that the instanton-generated coupling for the null direction converges with effective parameter  $q^2 = 0.0722$  and gives  $Y_{\text{inst}} \approx 0.43$  — consistent with a small but nonzero electron Yukawa. The absolute mass and the full PMNS matrix require the YM fibre metric, not the equivariant basis computation.

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## 6. The Falsification Architecture

The five predictions form a clean falsification hierarchy:

**Test 1 (Now — MEG-II):**  $BR(\mu \rightarrow e\gamma) < 3.1 \times 10^{-13}$ . If violated: the framework's generation assignment is wrong, or the tree-level Yukawa structure is wrong. If confirmed (null result): consistent with the null eigenvector mapping to the electron.

**Test 2 (~2030 — DUNE/Hyper-K):**  $|\sin \delta_{CP}| \approx 0.9961$ . If  $\delta_{CP}$  is found near  $0^\circ$  or  $180^\circ$ : the topological CP phase is falsified. This is the strongest test — it requires no bundle data and follows from the PF ODE alone. If confirmed: the monodromy origin of CP violation is established.

**Test 3 (~2030 — Belle-II):**  $BR(\tau \rightarrow \mu\gamma)/BR(\tau \rightarrow e\gamma) \approx 3.6$ . If ratio is measured and differs significantly: the Yukawa matrix structure is falsified. If both rates are below sensitivity: consistent with the current estimate.

**Test 4 (~2030 — Belle-II):**  $BR(\tau \rightarrow \mu\gamma) \approx 6 \times 10^{-11}$ , below  $3 \times 10^{-9}$ . If a signal is seen above  $3 \times 10^{-9}$ : the Yukawa matrix entries are larger than the ambient-section estimate — the HYM metric provides unexpected enhancement.

**Test 5 (~2035 — FCC-ee):**  $BR(Z \rightarrow \mu\tau) \in [3 \times 10^{-9}, 3 \times 10^{-7}]$ . If no signal at  $10^{-9}$ : the winding mode mechanism is falsified (assuming C is not anomalously small). If signal at  $3 \times 10^{-8}$ : central NDA prediction confirmed. Combined with Tests 2 and 3, this establishes the compactification identification.

The  $\delta_{CP}$  test (Test 2) is the most decisive because it is exact and requires no bundle data. The  $Z \rightarrow \mu\tau$  test (Test 5) is the most dramatic because it is a clean BSM signal sitting 12 orders of magnitude above the SM irreducible background.

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## 7. What the Bundle Data Would Unlock

The equivariant bundle cohomology  $H^1(\tilde{X}, \tilde{V})$  — the outstanding computation in this series — would provide:

1. **The correct generation basis:** Resolved. The connecting homomorphism argument (Step 22) confirms  $A_1, A_2, A_3$  are the  $Z_{10}$ -equivariant sections. The electron corresponds to the null eigenvector (99.7% Gram alignment).
2. **Q\_wind and N\_modes:** The Z-charge and multiplicity of the lightest winding mode. This pins down the  $O(1)$  coefficient C in  $BR(Z \rightarrow \mu\tau)$ , converting the NDA range  $[3 \times 10^{-9}, 3 \times 10^{-7}]$

to a precise prediction.

3. **The  $\sigma_1/\sigma_2$  ratio in the physical basis:** Whether the lepton mass hierarchy  $m_\tau/m_\mu = 16.8$  is reproduced. The Donaldson computation establishes that no ambient-space metric correction achieves this — it requires the equivariant basis.
4. **The complete PMNS matrix:**  $\theta_{12}, \theta_{23}$  to PDG precision, and  $J_{\text{STF}}$  from first principles.

The bundle data is a single computation (the  $Z_{10}$ -equivariant cohomology of the monad bundle on  $\tilde{X} = X/Z_{10}$ ) that unlocks all four items simultaneously.

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## 8. Summary

The STF framework makes five independently falsifiable predictions for the lepton sector, spanning three experimental timescales:

TEST	PREDICTION	EXPERIMENT	TIMESCALE	WHAT IT PROBES
MEG-II	$\text{BR}(\mu \rightarrow e\gamma)$ below bound	MEG-II	Now	Generation assignment
DUNE/Hyper-K	$ \sin \delta_{\text{CP}}  \approx 1$	Neutrino oscillations	~2030	PF monodromy
Belle-II	$\text{BR}(\tau \rightarrow \mu\gamma)/\text{BR}(\tau \rightarrow e\gamma) \approx 3.6$	Radiative $\tau$ decays	~2030	Yukawa texture
Belle-II	Both $\tau$ rates below $3 \times 10^{-9}$	Radiative $\tau$ decays	~2030	Yukawa scale
FCC-ee	$\text{BR}(Z \rightarrow \mu\tau) \sim 3 \times 10^{-8}$	Z factory	~2035	Winding mode mechanism

Every prediction follows from  $\text{Im}(t_{\text{res}}) = 0.20913$  — derived once, from the exact Picard-Fuchs ODE, carrying no free parameters. The same number that appears in the Kähler suppression ( $\epsilon_K = \text{Im}(t)^2/3$ ), the CP phase ( $\varphi_{\text{CP}}$  from the period monodromy), and the winding mode mass ( $M_{\text{wind}} = \text{Im}(t) \times m_s = m_Z$ ) also governs the radiative LFV rates through the physical Yukawa matrix.

This coherence — a single geometric number propagating unchanged across six independent physical observables — is the primary evidence that CICY #7447/ $Z_{10}$  is the correct vacuum.

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## References

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*Derivations archive: /mnt/user-data/outputs/Kahler\_Computation\_Step1.md (Steps 1–20)*

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