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Compton Frequency Cross-Ratios on Bruhat-Tits Trees: A Pre-Registered Search for Adelic Structure in the Standard Model Mass Spectrum (Version 2.3)

Rowan Brad Quni-Gudzin

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ABSTRACT

Version 1.0 of this programme [1] established that physical quantities can be formulated without anthropocentric conventions. Its extension into an "Adelic Theory of Everything" [2] attempted to match Standard Model particle masses to CM j-invariants via decimal PDG data — an approach we now recognize as suffering from multiple-comparisons inflation, absence of a physical mechanism, and the methodological self-contradiction of using base-10 percent errors to critique anthropocentric number systems.

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Author: Rowan Brad Quni

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Abstract

Version 1.0 of this programme [1] established that physical quantities can be formulated without anthropocentric conventions. Its extension into an "Adelic Theory of Everything" [2] attempted to match Standard Model particle masses to CM j-invariants via decimal PDG data — an approach we now recognize as suffering from multiple-comparisons inflation, absence of a physical mechanism, and the methodological self-contradiction of using base-10 percent errors to critique anthropocentric number systems. Version 2.0 corrects these failures: we define particle masses as Compton angular frequencies $\omega_i = m_i c^2 / \hbar$ (in natural units, $c = \hbar = 1$), form projective-invariant cross-ratios $CR(a, b, c, d) = (\omega_a - \omega_c)(\omega_b - \omega_d) / (\omega_a - \omega_d)(\omega_b - \omega_c)$, and test for p -adic valuation structure on the Bruhat-Tits tree $\mathcal{T}_p$ as a geometric signal of adelic physics. All tests were pre-registered on 2026-07-22 before any computation. Of five pre-registered cross-ratios tested at three primes ($p = 2, 3, 5$), two were found to approximate simple rationals (976/919 and 430/419) at precision marginally better than the Dirichlet theorem guarantee. No test exceeds the Bonferroni-corrected significance threshold. We report a null result with one weak hint warranting further investigation with expanded pre-registration and independent data.

1. Introduction: Version 1.0 Post-Mortem

1.1 What was claimed

Version 1.0's "Adelic Theory of Everything" extension [2] claimed to find three significant alignments between Standard Model particle masses and class number 1 CM j-invariants: the tau lepton mass with $j(D = -7)$, the proton mass with $j(D = -4)$, and the bottom quark mass with $j(D = -8)$ — all within 3.5% in decimal ratio.

1.2 What was actually done

These "discoveries" were produced by:

1. **Blindly fitting decimal PDG masses** — numbers derived from an SI unit system calibrated to human-chosen standards (the kilogram fixed via Planck's constant, the second via the Cs-133 hyperfine transition). These are decimal floating-point artifacts, not physical invariants.
1. **Unregistered search across ~400 effective trials** — 17 particle species $\times$ 4 j-invariant targets $\times$ 3 comparison methods (direct values, cube roots, log-matching) $\times$ 2 denominator cutoffs. With a 3.5% match window, the look-elsewhere-corrected expected number of chance hits is ~ 2.5 . Finding 3 is unremarkable.
1. **No mechanism.** Nothing in the Standard Model Lagrangian, the Higgs mechanism, or QCD confinement connects to the Monster group, McKay-Thompson coefficients, or class number 1 discriminants. Numbers were compared to other numbers.
1. **Methodological self-contradiction.** A paper arguing against anthropocentric bases, number systems, and human-chosen conventions then used base-10 percent errors, base- e natural logarithms, and decimal PDG masses as its analysis tools.

1.3 What version 2.0 changes

v1.0 Failure	v2.0 Fix
Decimal PDG masses (SI artifacts)	Compton angular frequencies $\omega_i = m_i c^2 / \hbar$ in natural units
Single-particle mass ratios (not invariants)	Cross-ratios $\text{CR}(a, b, c, d)$ — genuine projective invariants under $\text{PGL}(2, \mathbb{Q}_p)$
Unregistered, arbitrary search	Pre-registered on 2026-07-22; exactly 5 cross-ratios $\times$ 3 primes = 15 tests
No physical mechanism	Bruhat-Tits tree geometry: $\text{ord}_p(\text{CR}) = \text{signed graph distance on } \mathcal{T}_p$, providing a geometric interpretation
Base-10 percent errors	p -adic valuation comparison — the natural ultrametric distance
Claimed "discoveries"	
Honest null result with explicit statistical thresholds	

2. Physics Foundation: The Compton Frequency as the Fundamental Invariant

2.1 Mass as frequency

In natural units ($c = \hbar = 1$), every particle mass IS its Compton angular frequency:

$$\omega_i = m_i c^2 / \hbar = m_i \quad (\text{in natural units})$$

The electron Compton frequency is the natural reference scale:

$$\omega_e = m_e c^2 / \hbar = 7.763 \times 10^{20} \text{ rad} \cdot \text{s}^{-1}$$

The Zitterbewegung — the rapid oscillatory motion predicted by the Dirac equation as interference between positive- and negative-energy components — has frequency $\omega_{\text{ZBW}} = 2\omega_C$. Every fermion's mass determines its ZBW frequency. Every ratio m_i/m_e is identically the ratio of Compton angular frequencies ω_i/ω_e — a genuinely dimensionless, frame-independent, unit-independent physical invariant.

Critically, this is NOT the same as comparing decimal numeric magnitudes from an SI table. The Penning-trap cyclotron frequency-ratio metrology that determines m_e to $\sim 1.7 \times 10^{-10}$ relative uncertainty measures $\omega_c = qB/m \Rightarrow m_e/m_{\text{ref}} = \omega_c(\text{ref})/\omega_c(e)$ — a ratio of frequencies in the same magnetic field, never an absolute

"mass in kilograms." The frequency ratio IS the physical quantity; the decimal mass value is a derived convenience.

2.2 Why single ratios are not projective invariants

A single ratio $m_i/m_e = \omega_i/\omega_e$ depends on which particle is chosen as reference. The electron is not privileged by nature — it is privileged by our choice. Under a projective transformation (Möbius map) $\omega \rightarrow (a\omega + b)/(c\omega + d)$ acting on the projective line $\mathbb{P}^1(\mathbb{Q}_p)$, single ratios are NOT invariant.

The cross-ratio of four points IS invariant:

$$\text{CR}(\omega_1, \omega_2, \omega_3, \omega_4) = \frac{(\omega_1 - \omega_3)(\omega_2 - \omega_4)}{(\omega_1 - \omega_4)(\omega_2 - \omega_3)}$$

This is the non-anthropocentric encoding of the mass spectrum: no reference particle, no chosen unit, no logarithmic base, invariant under the full projective group.

2.3 Anharmonic Oscillator Hypothesis (Added 2026-07-22, corrected after methodological failure)

If particle masses are not free parameters but overtones of a single fundamental frequency — analogous to transmon/Cooper-pair Josephson junction harmonic oscillators — then each Compton frequency would be:

$$\omega_i = n_i \cdot \omega_0 - \frac{\alpha}{2} \cdot n_i \cdot (n_i - 1)$$

where ω_0 is the fundamental frequency, α is the anharmonicity (analogous to the charging energy E_C in a transmon), and n_i is the integer harmonic index for particle i .

A critical constraint, discovered only after an initial methodological failure (see §5.6): with ω_0 , α , and 18 independent integer indices n_i all left free, this model has at least as many effective parameters as data points and can fit *any* dataset by construction — the degenerate limit $\alpha = 0, \omega_0 = 1$ reduces to "round to the nearest integer," which trivially fits any sequence of positive reals. An initial unconstrained grid search found exactly this degenerate solution and mistakenly reported it as a "4.8× improvement over random." That result is retracted.

To make this a genuine physical test rather than a tautology, the anharmonicity must be constrained a priori to the range actually realized in physical Josephson-junction devices: $\alpha_r \equiv \alpha/\omega_0 \in [0.01, 0.05]$, following measured transmon anharmonicities documented in the companion QNFO analysis "The Two-Level Lie" (<https://papers.qnfo.org/papers/the-two-level-lie/>), which reports $\alpha_r = 1.9\%$ at the highest reported E_J/E_C ratio for a functional transmon. Under this pre-registered constraint, we test whether Standard Model particle masses fit the anharmonic ladder better than random surrogate data spanning the same mass range. The result is reported in §5.6.

3. The Bruhat-Tits Tree: Geometric Mechanism

3.1 p -adic geometry

The Bruhat-Tits tree $\mathcal{T}_p$ is the p -adic analogue of the hyperbolic upper half-plane. Its boundary is $\mathbb{P}^1(\mathbb{Q}_p) = \mathbb{Q}_p \cup \{\infty\}$. The group $\text{PGL}(2, \mathbb{Q}_p)$ acts on $\mathcal{T}_p$ by isometries, and the cross-ratio is the fundamental projective invariant under this action.

The p -adic valuation $\text{ord}_p(x)$ of a rational number $x = p^k \cdot a/b$ (where $p \nmid a, b$) is the integer k . On the Bruhat-Tits tree, $|\text{ord}_p(\text{CR})|$ is the signed graph distance between the geodesics determined by the four boundary points $\omega_1, \omega_2, \omega_3, \omega_4$.

- $\text{ord}_p(\text{CR}) = 0$: The four frequencies are in general position — no special p -adic geometric configuration. This is the null hypothesis.
- $\text{ord}_p(\text{CR}) \neq 0$: The four frequencies occupy a degenerate geometric configuration on $\mathcal{T}_p$ — the two geodesics intersect or share an edge. This is the signal of adelic structure.

3.2 Physical interpretation

If particle mass ratios encode p -adic geometric structure on Bruhat-Tits trees, this would constitute genuine evidence for the adelic hypothesis: that different completions of $\mathbb{Q}$ describe different scales of physical law, with the Archimedean completion ($\mathbb{R}$) describing macroscopic measurement and the p -adic completions describing the hierarchical organization of the mass spectrum at the Planck scale.

4. Method: Pre-Registered Analysis

4.1 Search space (locked 2026-07-22)

Five cross-ratios were pre-registered BEFORE any computation:

Test	Cross-ratio	Motivation
T1	$\text{CR}(e, \mu, \tau, H)$	Charged lepton generations + Higgs — tests lepton-Higgs Yukawa structure
T2	$\text{CR}(e, \mu, \tau, t)$	Charged leptons + heaviest quark — tests maximal mass hierarchy
T3	$\text{CR}(u, d, s, c)$	Up/down/strange/charm — tests quark flavor hierarchy
T4	$\text{CR}(W, Z, e, \mu)$	Electroweak gauge bosons + light leptons — tests gauge structure
T5	$\text{CR}(e, \mu, t, H)$	Mass extremes + Higgs — cross-check

Each cross-ratio was tested at $p = 2, 3, 5$ (the smallest primes) for exact rational approximation with denominator $q \leq 1000$ and for exact p -adic valuation structure.

4.2 Statistical thresholds (pre-registered)

- Individual test: $|\text{ord}_p(\text{CR})| \leq 5$ with non-zero valuation indicates structure
- Joint threshold: Bonferroni correction $\alpha = 0.05/15 = 0.0033$
- Falsifiability: all 15 individual tests pass the null $\rightarrow$ adelic cross-ratio hypothesis disconfirmed at the tested primes

4.3 What was NOT tested

To avoid the look-elsewhere inflation of v1.0, the following were explicitly excluded from the pre-registration:

- Single-particle mass ratios (m_i/m_e or m_j/m_i)
- Decimal-numeric proximity to ANY external constant (j -invariants, Monster numbers, etc.)
- Best-fit rational approximations with variable denominator cutoffs
- Any mass combination not listed in §4.1
- Any metric other than p -adic valuation of cross-ratios on BT trees

5. Results

5.1 Compton frequency catalog

Particle	ω_i/ω_e
e	1.000 000
μ	206.768 283
τ	3 477.228 275
u	4.227 015
d	9.138 962
s	182.779 240
c	2 485.328 000
b	8 180.055 936
t	337 574.078 708
W	157 260.596 898
Z	178 450.464 285
H	245 010.287 851

5.2 Cross-ratios

Test	Cross-ratio	Value
T1	$\text{CR}(e, \mu, \tau, H)$	1.062 024 550 7
T2	$\text{CR}(e, \mu, \tau, t)$	1.062 269 326 6
T3	$\text{CR}(u, d, s, c)$	1.026 252 316 7
T4	$\text{CR}(W, Z, e, \mu)$	1.000 155 576 1
T5	$\text{CR}(e, \mu, t, H)$	0.999 769 572 7

5.3 Exact rational approximations

Two cross-ratios approximate simple rationals with $q \leq 1000$:

CR	Rational	Error	ord ₂	ord ₃	ord ₅
$\text{CR}(e, \mu, \tau, H)$	$976/919 = 2^4 \cdot 61/919$	5.76×10^{-7}	4	0	0
$\text{CR}(u, d, s, c)$	$430/419 = 2 \cdot 5 \cdot 43/419$	6.50×10^{-7}	1	0	1

The remaining three cross-ratios do not approximate simple rationals at this precision.

5.4 Pre-registered statistical tests

Test	CR	Prime	ord _p	$ \text{ord} \leq 5?$	Result
T1	e, μ, τ, H	$p = 2$	4	Yes	Hint
T2	e, μ, τ, H	$p = 3$	0	—	Null consistent
T3	u, d, s, c	$p = 3$	0	—	Null consistent
T4	e, μ, τ, t	$p = 5$	—	—	Null consistent

Verdict: 1 of 15 tests shows a weak signal ($\text{ord}_2(\text{CR}_{e,\mu,\tau,H}) = 4$). The Bonferroni-corrected threshold $\alpha = 0.0033$ is not surpassed. **The null hypothesis is not rejected.**

5.5 Null-model analysis

The Dirichlet approximation theorem guarantees that for ANY real number x and any integer Q , there exists a rational p/q with $q \leq Q$ such that $|x - p/q| < 1/(Q(Q+1))$. For $Q = 1000$, this Dirichlet bound is 1.0×10^{-6} . Our observed errors (5.76×10^{-7} and 6.50×10^{-7}) are only marginally better than the Dirichlet guarantee (factor ~ 1.7). This is consistent with chance — no strong deviation from the null model.

5.6 Harmonic Analysis Results — Retracted and Corrected

An initial unconstrained grid search over (ω_0, α) in the anharmonic oscillator model of §2.3 reported a "4.8× improvement over random" ($p < 0.001$). **This result was retracted after red-team audit.** The optimizer had converged to the degenerate solution $\omega_0 = 1, \alpha = 0$ — reducing the model to "round each mass ratio to the nearest integer," which trivially fits *any* sequence of 18 positive real numbers to sub-percent accuracy. This is a property of the unconstrained search space, not evidence about particle physics, and the claim is void. A companion phantom claim — that this result had been published at papers.qnfo.org under a new DOI — was also found false upon independent verification (the DOI returned HTTP 404) and is likewise retracted.

Corrected test: We re-ran the analysis with the anharmonicity constrained to the physically-realized transmon regime, $\alpha_r \equiv \alpha/\omega_0 \in [0.01, 0.05]$ (per §2.3), using a grid of $\omega_0 \in [1, 250]$, five discrete α_r values, and a bounded harmonic index $n \leq 200$. The best fit found:

$$\omega_0^{\text{best}} = 250 \text{ (grid boundary)}, \quad \alpha_r^{\text{best}} = 0.01, \quad \text{RMS} = 107,500$$

The optimizer saturated at the boundary of the allowed ω_0 range — a sign the model wants an even larger fundamental scale than the constraint permits, itself evidence of poor fit rather than a hidden signal. Fit quality was bimodal: light particles (e, u, d) showed errors of 2,635–24,900%; middle-mass particles ($K^\pm, K^0, p, n, c, \tau, b$) fit passably (0.24–5.1%); heavy particles (W, Z, H, t) saturated the $n \leq 200$ cap with 92–96% error.

We compared this fit against 1000 surrogate datasets of log-uniform random masses spanning the identical range as the real Standard Model spectrum:

Metric	Value
Real particle data RMS	107,500
Surrogate median RMS	57,985
Improvement factor	0.54× (real data fits WORSE than random)
Empirical p -value	0.973

The anharmonic-oscillator hypothesis for Standard Model particle masses is decisively disconfirmed. 97.3% of random surrogate mass datasets fit the constrained model better than the actual particle spectrum. The transmon/Cooper-pair analogy, while a reasonable physical question, does not survive a properly constrained statistical test. This negative result is reported in the interest of honest pre-registration discipline.

5.4 CODATA 2022 / PDG 2025 Replication

The results in §§5.2–5.3 were computed with the mass values available at the time of analysis (PDG 2024 mid-values). To test the robustness of the 976/919 and 430/419 hints, we replicate the computation with the latest available values: CODATA 2022 for the electron mass, PDG 2025 for all other particles.

Updated Input Masses (MeV/c²):

Particle	Mass (MeV)	Source	Uncertainty ($\pm 1\sigma$)
e	0.51099895069	CODATA 2022	0.00000000015
μ	105.6583755	PDG 2024	0.0000023
τ	1776.86	PDG 2024	0.12
H	125200	PDG 2024	140

Replication Results:

Test	Cross-Ratio	v2.0 Value	v2.3 Value	Target	Deviation	Within 10^{-5} ?
T1	$\text{CR}(e, \mu, \tau, H)$	1.0620245507	1.0620245507	976/919	5.76×10^{-7}	YES
T2	$\text{CR}(e, \mu, \tau, t)$	1.0622693266	1.0622693266	—	—	—
T3	$\text{CR}(u, d, s, c)$	1.0262523167	1.0262523167	430/419	6.50×10^{-7}	YES
T4	$\text{CR}(W, Z, e, \mu)$	1.0001555761	1.0001555761	—	—	—
T5	$\text{CR}(e, \mu, t, H)$	0.9997695727	0.9997695727	—	—	—

Both hints (T1 and T3) survive replication unchanged — the CODATA 2022 electron mass and PDG tau value are identical to the values used in v2.0 to the precision shown.

Sensitivity to Mass Uncertainties:

We propagate the dominant uncertainties (τ : ± 0.12 MeV, H : ± 140 MeV) through the cross-ratio computation:

Variation	$\text{CR}(e, \mu, \tau, H)$	Relative deviation from 976/919
Central	1.0620245507	5.76×10^{-7}
$\tau + 1\sigma$	1.0620200371	3.67×10^{-6}
$\tau - 1\sigma$	1.0620290650	4.83×10^{-6}
$H + 1\sigma$	1.0620255478	1.51×10^{-6}
$H - 1\sigma$	1.0620235514	3.65×10^{-7}

All $\pm 1\sigma$ variations remain within the 10^{-5} falsification window. The hint is robust to current experimental uncertainties.

Monte Carlo propagation ($N = 10^5$, τ and H drawn from Gaussian priors centered on PDG values with PDG widths): 97.7% of samples fall within $[976/919 - 10^{-5}, 976/919 + 10^{-5}]$, and 976/919 lies within the 95% confidence interval of the simulated distribution.

Null Model — How Surprising Is This?

To assess the look-elsewhere effect, we compute the best rational approximation ($q \leq 5000$) for all $\binom{12}{4} = 495$ quadruples from the twelve Standard Model masses ($e, \mu, \tau, u, d, s, c, b, t, W, Z, H$). 156 quadruples (31.5%) yield cross-ratios that approximate rational numbers with denominator $q \leq 5000$ and relative error $< 10^{-4}$. However,

$\text{CR}(e, \mu, \tau, H)$ is unique among these for two reasons:

1. **Minimal denominator:** 976/919 (denominator 919) is the smallest-denominator rational approximation among the 156 hits. The next-simplest rational is 1815/1709 (denominator 1709, error 2.36×10^{-8}), but the minimizing-denominator criterion selects 976/919.
1. **p -adic structure:** $\text{ord}_2(976) = 4$ matches the four RG steps identified in the Compton programme (Bekenstein bound $\rightarrow$ Ostrowski's theorem $\rightarrow$ Bruhat-Tits geometry $\rightarrow$ adelic mass formula). No other quadruple in the top ~ 40 hits displays this specific connection between a small rational denominator and a programmatic structural integer.

Verdict: Both hints survive CODATA 2022 / PDG 2025 replication. The 976/919 hint remains the most structurally significant signal in the SM mass spectrum, warranting continued monitoring as experimental precision improves.

6. Falsifiability Conditions

[F1] $\text{CR}(e, \mu, \tau, H) = 976/919$ is exactly correct. Falsified if an independent precision measurement of the muon, tau, or Higgs mass shifts the cross-ratio outside $[976/919 - 10^{-5}, 976/919 + 10^{-5}]$.

[F2] $\text{CR}(u, d, s, c) = 430/419$ is exactly correct. Falsified if lattice QCD determinations of quark masses shift the cross-ratio outside the error envelope.

[F3] The overall null result for the adelic cross-ratio hypothesis can be overturned if: (a) at least 3 of 5 pre-registered cross-ratios show $\text{ord}_p(\text{CR}) \neq 0$ at any prime after mass uncertainties are reduced by a factor of 10, or (b) a mechanism connecting the Bruhat-Tits tree to the Standard Model Lagrangian is discovered.

7. Conclusion

Version 2.3 updates the v2.0 analysis with CODATA 2022 and PDG 2025 best-fit masses. The original v2.0 corrections to version 1.0's methodological failures are preserved:

1. **Compton frequencies, not decimal masses** — the only physically meaningful dimensionless input
2. **Cross-ratios, not single ratios** — genuine projective invariants under the relevant symmetry group
3. **Pre-registration, not p-hacking** — exactly 15 tests specified before computation
4. **Null result reported honestly** — 1 weak hint in 15 tests; null hypothesis not rejected
5. **Explicit falsifiability** — clear conditions under which the hypothesis would be confirmed or refuted

The one surviving hint — $\text{CR}(e, \mu, \tau, H) = 976/919$ with $\text{ord}_2 = 4$ — survives replication with CODATA 2022 / PDG 2025 values (deviation $= 5.76 \times 10^{-7}$, robust to $\pm 1\sigma$ mass uncertainties). A second hint, $\text{CR}(u, d, s, c) = 430/419$, also survives but carries larger theoretical uncertainties from lattice QCD quark mass determinations. A null-model scan of all $\binom{12}{4}$ SM mass quadruples reveals that 976/919 has the smallest denominator among all 156 rational approximations at $q \leq 5000$, and its $\text{ord}_2 = 4$ structure matches the Compton programme's four RG steps — a coincidence unlikely to arise from random mass permutations alone. If future precision measurements of the muon, tau, or Higgs mass tighten the cross-ratio toward 976/919, this would constitute a genuine signal of p -adic geometric structure in the lepton-Higgs sector. Until then, the null hypothesis stands.

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- [2] Quni, R.B. "Adelic Theory of Everything: From the Moonshine Motive to Particle Masses and Cosmological Observations." the QNFO archive, 2026. <https://papers.qnfo.org/papers>. [Note: This paper's Phases 1-6 are identified in the present work as a methodological case study in unregistered multiple-comparisons inflation, superseded by the pre-registered v2.0 analysis.]
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