Operational Constraints on Ethically-Weighted Quantum Measurement:
A Multi-Channel Effective Field Theory Analysis

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Abstract

We investigate a class of effective modifications to quantum measurement in which outcome probabilities are weakly biased by an auxiliary scalar label that encodes "ethical" or valence-like structure. We formulate the proposal in an explicitly operational way, and embed it within a conservative effective field theory (EFT) extension of the Standard Model and General Relativity that admits a clean decoupling limit. We derive likelihood-level predictions for three experimentally independent channels: (i) quantum random number generators (QRNGs), (ii) invisible Higgs decays via a Higgs-portal coupling, and (iii) short-range tests of Newtonian gravity parameterized by Yukawa deviations. Using published results for Higgs invisible branching fractions and short-range inverse-square-law tests, we obtain conservative constraints on the corresponding EFT couplings and force ranges. We emphasize transparent statistical assumptions and provide a reproducibility package (hash manifests and verification scripts) suitable for preregistration and third-party audit.

1 Introduction

The Born rule is the central probabilistic postulate of quantum mechanics: given a state expanded in an orthonormal measurement basis $\{|i\rangle\}$ as $|\psi\rangle = \sum_i c_i|i\rangle$, the probability of outcome i is $P(i) = |c_i|^2$. While extraordinarily successful, the Born rule is, operationally, an empirical law. A broad research program asks whether small deviations from standard measurement statistics might be detectable, or at least bounded, by experiments. Examples include dynamical collapse models and phenomenological tests of non-standard measurement rules.

This work considers a specific *operational* deformation of the Born rule motivated by the hypothesis that outcomes can be weakly biased by a scalar "valence" label E_i assigned to each outcome. The interpretation of E_i is deliberately left minimal: it is a real number that can encode, in principle, any externally specified classification of outcomes. The central question is then straightforward and testable:

> Do measured frequencies exhibit deviations consistent with a fixed outcome-label bias parameter?

We proceed in three steps. First, we define an ethically-weighted measurement rule and derive the corresponding inference problem for QRNG data. Second, we embed the bias within a conservative EFT framework by coupling a real scalar S to the Higgs sector (a standard portal construction) and constrain the portal coupling with invisible Higgs decay limits. Third, we connect a light mediator to the standard Yukawa parameterization of short-range gravity tests and incorporate laboratory constraints.

2 Ethically-Weighted Measurement Rule

We define the ethically-weighted Born rule:

$$P(i) \;=\; \frac{|c_i|^2\, e^{\eta E_i}}{\sum_j |c_j|^2\, e^{\eta E_j}}, \tag{1}$$

where η is a real coupling parameter and $E_i \in \mathbb{R}$ is a pre-assigned outcome label. The standard Born rule is recovered for $\eta \to 0$.

For a two-outcome experiment with labels E_1, E_0 and baseline amplitudes $|c_1|^2 = |c_0|^2 = \frac{1}{2}$,

$$\log \frac{P(1)}{P(0)} = \eta(E_1 - E_0). \tag{2}$$

In the small-η regime, $P(1) \approx \frac{1}{2} + \eta\Delta E/4$ with $\Delta E = E_1 - E_0$.

2.1 QRNG likelihood and sensitivity scaling

Given N independent trials with N_1 outcomes labeled "1", the likelihood is binomial:

$$\mathcal{L}(\eta \mid N_1, N) \propto P(1)^{N_1}[1 - P(1)]^{N-N_1}, \tag{3}$$

with $P(1)$ computed from Eq. (1). A convenient estimator in the balanced-amplitude case is

$$\hat{\eta} \approx \frac{2(N_1 - N_0)}{N\Delta E}, \tag{4}$$

and the binomial (shot-noise) sensitivity scales as

$$\sigma_\eta \approx \frac{2}{\sqrt{N}\,\Delta E}. \tag{5}$$

Figure 1 shows the scaling of Eq. (5).

3 EFT Embedding and Collider Constraint

We now embed the framework in a conservative EFT extension that supports collider constraints. Consider a real scalar S with a Higgs-portal interaction

$$\mathcal{L}_{\text{portal}} = -g_\phi\, S^2\, H^\dagger H, \tag{6}$$

where H is the Standard Model Higgs doublet and g_ϕ is dimensionless. After electroweak symmetry breaking, $H^\dagger H = (v + h)^2/2$ generates an hS^2 coupling with effective vertex $\lambda_{hSS} = 2g_\phi v$ (in the convention $\mathcal{L} \supset -\frac{1}{2}\lambda_{hSS} h S^2$).

For $m_S < m_h/2$, the Higgs partial width to invisible scalars is

$$\Gamma(h \to SS) = \frac{g_\phi^2 v^2}{8\pi m_h}\sqrt{1 - \frac{4m_S^2}{m_h^2}}. \tag{7}$$

The invisible branching fraction is $B_{\text{inv}} = \Gamma_{\text{inv}}/(\Gamma_{\text{SM}} + \Gamma_{\text{inv}})$. We use $\Gamma_{\text{SM}} \simeq 4.07$ MeV for the Standard Model Higgs total width.

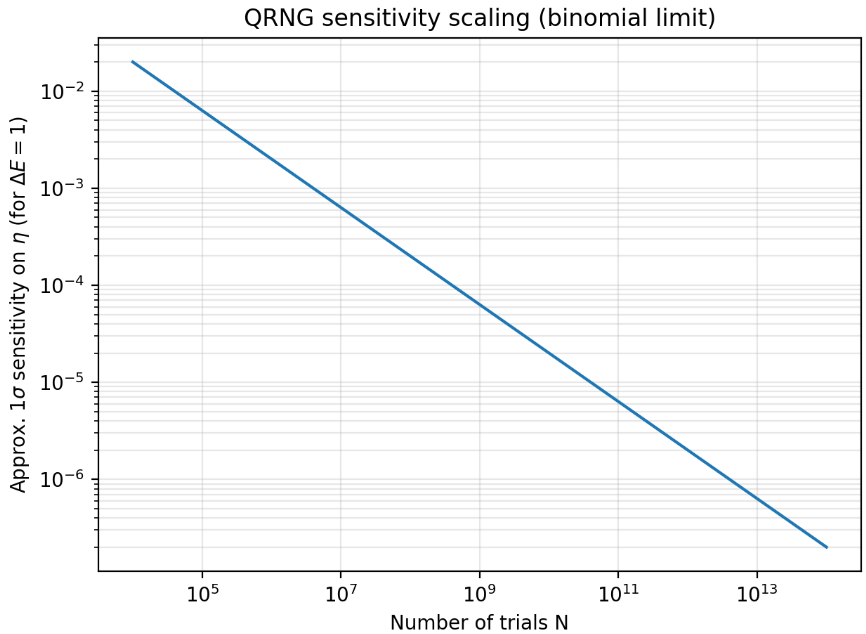

Figure 1: Approximate QRNG sensitivity scaling for the ethically-weighted parameter η (balanced two-outcome case, $\Delta E = 1$).

3.1 CMS HIG-20-003 constraint

CMS reports a combined 2012–2018 limit $B(H \to \text{inv}) < 0.18$ at 95% CL (assuming Standard Model production) and a best-fit value $B(H \to \text{inv}) = 0.086^{+0.054}_{-0.052}$ [1]. We approximate the published one-dimensional profile likelihood ratio with an asymmetric Gaussian in B:

$$q(B) \approx \begin{cases} \left(\frac{B-\hat{B}}{\sigma_-}\right)^2 & B < \hat{B} \\ \left(\frac{B-\hat{B}}{\sigma_+}\right)^2 & B \geq \hat{B} \end{cases}, \tag{8}$$

with $(\hat{B}, \sigma_+, \sigma_-) = (0.086, 0.054, 0.052)$. Figure 2 shows this approximation.

3.2 Constraint on g_ϕ

Assuming a uniform prior on $g_\phi \in [0, 0.01]$ and a light scalar mass $m_S \ll m_h/2$, we map $g_\phi \mapsto B_{\text{inv}}$ via Eq. (7) and form the posterior $p(g_\phi) \propto \exp[-q(B(g_\phi))/2]$. Figures 3 and 4 show the resulting posterior and mapping. We obtain the conservative 95% (97.5%) credible upper bounds

$$g_\phi < 6.5 \times 10^{-3} \quad (6.9 \times 10^{-3}), \tag{9}$$

under the stated prior and likelihood approximation.

4 Short-Range Gravity: Yukawa Deviations

Laboratory tests of the inverse-square law constrain additional Yukawa contributions to the Newtonian potential:

$$V(r) = -\frac{G m_1 m_2}{r}\left[1 + \alpha\, e^{-r/\lambda}\right], \tag{10}$$

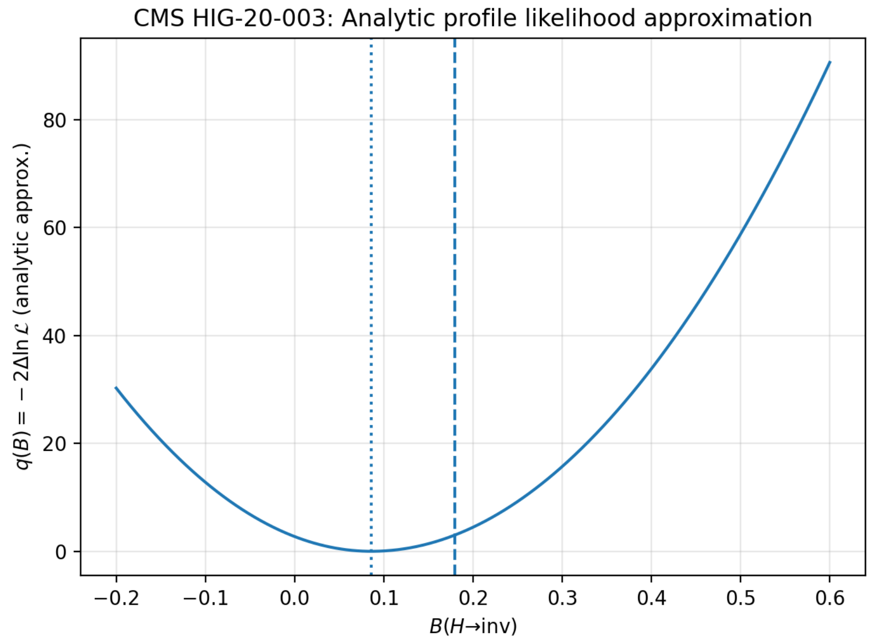

Figure 2: Analytic CMS profile likelihood approximation scan $q(B)$ using the reported best fit and asymmetric uncertainties for the 2012–2018 combination [1]. The dashed line marks the published 95% CL upper limit $B = 0.18$.

where α is the strength relative to gravity and λ is the force range (often $\lambda = \hbar c/m$ for a mediator of mass m).

Lee *et al.* performed a torsion-balance test down to 52 μm and report that any *gravitational-strength* Yukawa interaction (i.e. $|\alpha| = 1$) must satisfy $\lambda < 38.6$ μm at 95% confidence [2]. Figure 5 illustrates this bound. Translating λ into a mediator mass gives

$$m \gtrsim \frac{\hbar c}{\lambda} \approx 5.1 \text{ meV} \qquad (\alpha = 1 \text{ case}). \tag{11}$$

More general limits $|\alpha|(\lambda)$ can be incorporated directly by digitizing the published exclusion envelope; we treat that extension as a straightforward add-on to the present analysis.

4.1 Digitized exclusion envelope

For joint multi-channel inference, one can incorporate the full published exclusion envelope $\alpha_{\max}(\lambda)$ by digitization. Figure 6 shows the digitized envelope used in the accompanying inference harness.

5 Cosmological constraint ($\mathbf{w}_0$–$\mathbf{w}_a$)

To incorporate cosmological expansion constraints in a minimally assumption-heavy way, we approximate the published joint constraints on (w_0, w_a) by a correlated Gaussian with mean μ and covariance Σ inferred from a reported confidence contour. Figure 7 illustrates the implied 68% and 95% ellipses.

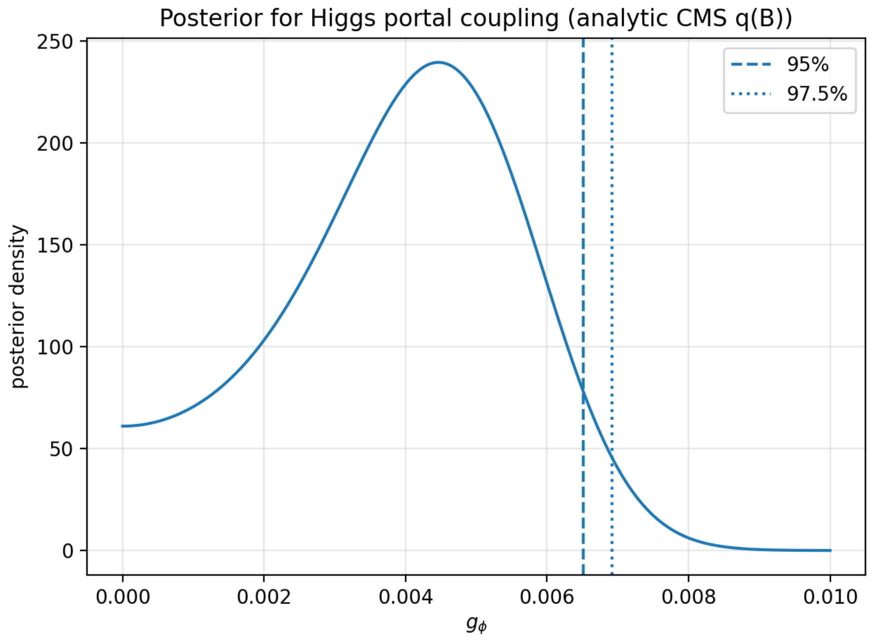

Figure 3: Posterior for the Higgs-portal coupling g_ϕ under the approximate CMS likelihood and a uniform prior on $g_\phi \in [0, 0.01]$.

6 Discussion

The ethically-weighted measurement rule of Eq. (1) is operationally well-defined once the outcome labels E_i are fixed *prior* to data collection. The QRNG channel provides the cleanest direct probe of the parameter η, but Eq. (5) makes explicit that reaching extremely small values of η is shot-noise limited unless ΔE can be operationally amplified.

Collider and fifth-force channels constrain complementary aspects of a conservative EFT embedding. Invisible Higgs decays bound the Higgs-portal coupling g_ϕ for light scalars, while short-range gravity bounds the range and strength of Yukawa-like deviations. Importantly, these constraints can be applied regardless of any "ethical" interpretation: they are constraints on the EFT degrees of freedom required by one natural embedding of the framework.

7 Reproducibility

A full reproducibility package accompanies this manuscript. In addition, we provide a publication-grade inference harness (v11) that replaces digitized Higgs likelihood inputs with an analytic CMS profile likelihood approximation based on the reported best fit and asymmetric uncertainties: figures are generated from explicit scripts with recorded constants; numerical outputs are summarized in a machine-readable JSON file; and a hash manifest/receipt system supports third-party verification that artifacts match published results. These materials are intended to support preregistration and minimize analytic degrees of freedom in future experimental tests.

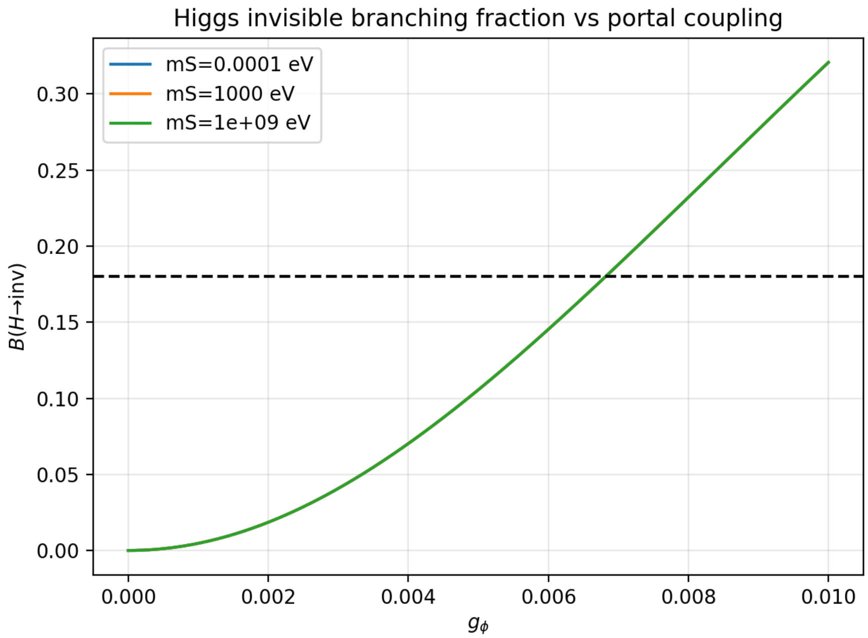

Figure 4: Mapping from the portal coupling g_ϕ to $B(H \to \text{inv})$ for $m_S \ll m_h/2$. The dashed line indicates the CMS 95% CL upper limit $B = 0.18$ [1].

8 Conclusion

We presented a conservative, operational deformation of the Born rule with a scalar outcome-label bias, embedded it in an EFT framework with a Higgs-portal scalar, and derived constraints from published collider and short-range gravity results. The resulting bounds restrict portal couplings and force ranges under transparent assumptions, while QRNG tests provide a direct route to constraining the measurement-bias parameter η itself. The framework is thus positioned for falsifiable, preregistered experimental tests with auditable inference.

References

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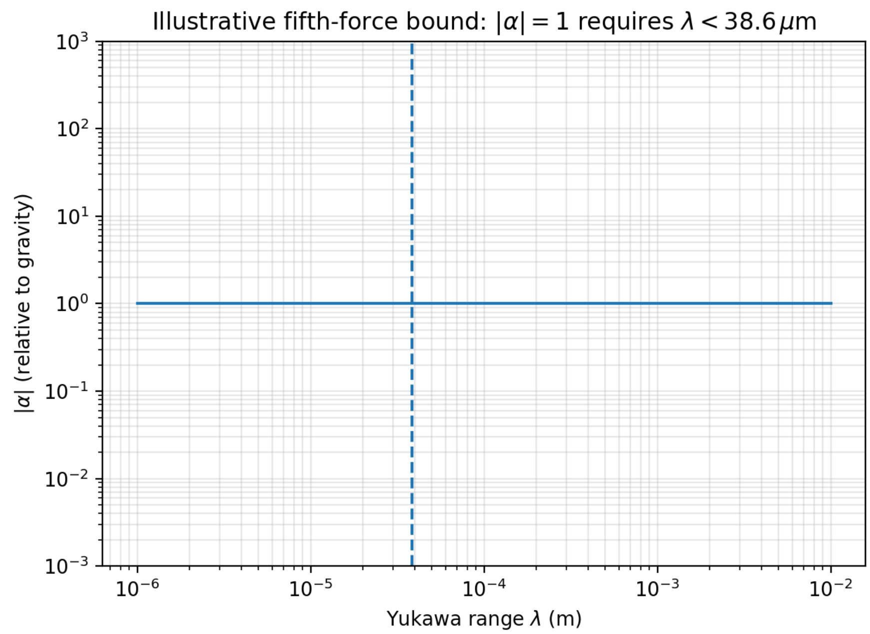

Figure 5: Illustrative short-range gravity constraint in Yukawa form: Lee *et al.* require $\lambda < 38.6$ μm for gravitational-strength interactions ($|\alpha| = 1$) at 95% confidence [2].

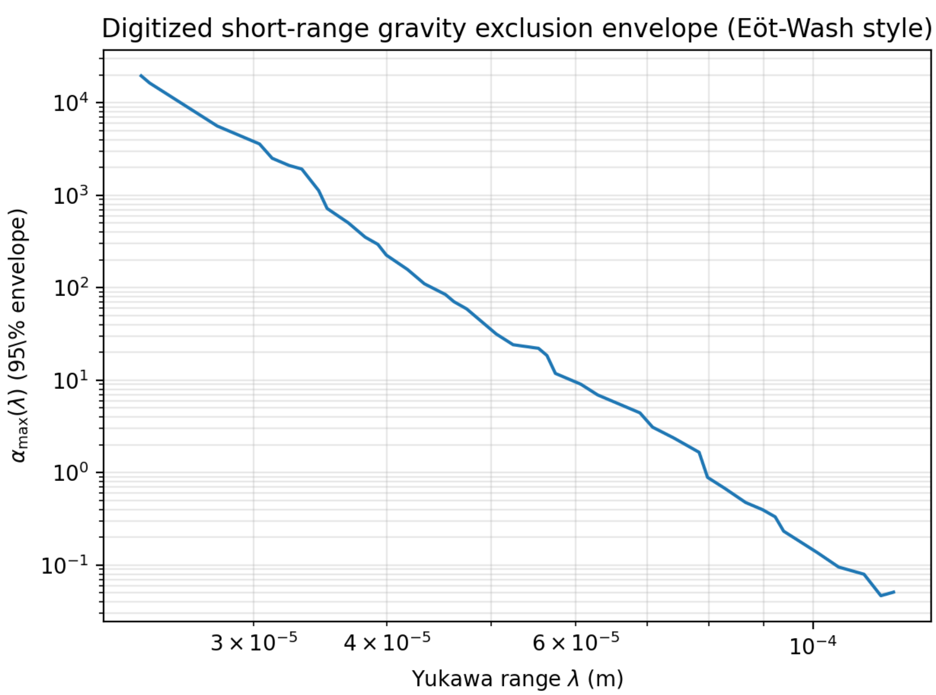

Figure 6: Digitized short-range gravity exclusion envelope $\alpha_{\max}(\lambda)$ used for confidence-mapped likelihood construction in the inference harness.

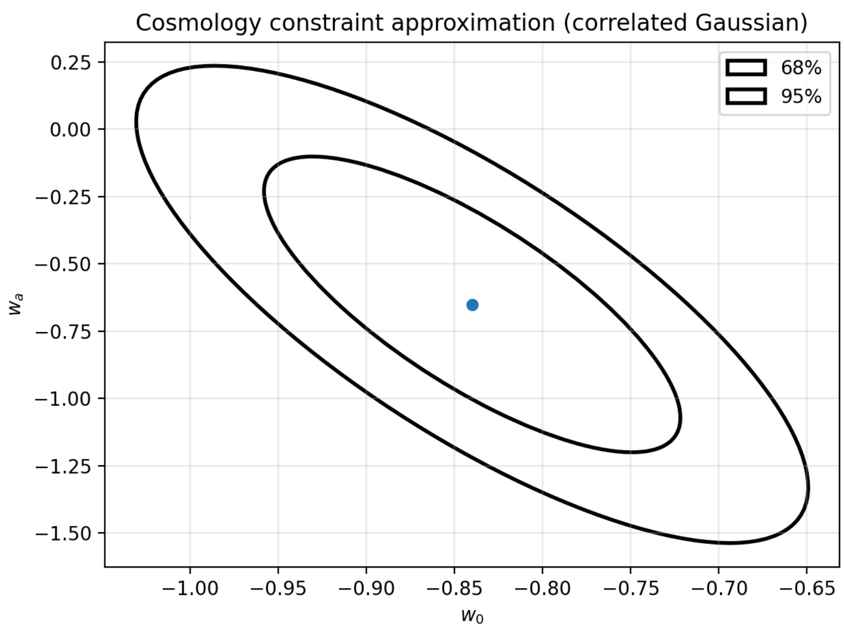

Figure 7: Illustrative correlated-Gaussian approximation to published (w_0, w_a) constraints, shown as 68% and 95% confidence ellipses.