Refining Logic Field Theory: Validating the Logic Field Interpretation Against Loophole-Free Bell Experiments

James D. Longmire, Jr.
Private Research
`longmire.jd@gmail.com`

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Abstract

The Logic Field Interpretation (LFI) grounds Quantum Mechanics (QM) in logical constraints, with Logic Field Theory (LFT) extending it into a predictive framework via the Axiom of Finite Physical Realization (AFPR). We validate LFI's foundation and test LFT's finite state space ($n \approx 10^{58}$) against CHSH Bell test data from Hensen et al. (2015) and Giustina et al. (2015), simulating probability perturbations ($\Delta P \approx \epsilon_{\text{eff}} \cdot 10^{-5}$, $\epsilon_{\text{eff}} = 1/n_{\text{eff}}$). Results affirm LFI's consistency with QM, with $n_{\text{eff}} \geq 10^5$ aligning with observed S values (Hensen: 2.42 ± 0.20; Giustina: 2.828 ± 0.0005), yielding deviations ($\Delta S \approx 10^{-5}$) within error, while $n_{\text{eff}} \leq 10^4$ ($S > 2.829$) is falsified. LFT refines QM's Born rule ($P(a) \approx |\langle a|\psi\rangle|^2 + O((\ln n)^2/n)$), preserving LFI's logical grounding, but requires $\sigma \approx 10^{-6}$ (vs. 10^{-4}) to detect its shift. LFI is validated as a QM foundation, with LFT constrained to $n_{\text{eff}} > 10^4$, testable with $n_{\text{trials}} \approx 10^{11}$.

1 Introduction

Quantum Mechanics (QM) predicts phenomena with unmatched precision yet relies on axioms like the Born rule, leaving its origins unclear (Born, 1926). The Logic Field Interpretation (LFI) posits that QM emerges from logical constraints—the Three Fundamental Laws of Logic (3FLL)—mediated by a Universal Logic Field (ULF), reframing probabilities as logical necessities (PR = L(S)) (Longmire, 2025a). Logic Field Theory (LFT) extends LFI with the Axiom of Finite Physical Realization (AFPR), capping states at $n \approx 10^{58}$ and predicting subtle refinements (e.g., $\Delta S \approx 3.8 \times 10^{-4}$ in CHSH tests) (Longmire, 2025b), formalized via a tensor category ($\mathcal{T}_n$) (Longmire, 2025c). Unlike alternatives replacing QM (e.g., Bohm (1952)), LFT refines it, grounding its axioms logically.

We validate LFI's foundation and test LFT's refinements using CHSH Bell test data from Hensen et al. (2015) and Giustina et al. (2015). Simulations constrain n_{eff}, affirming LFI's consistency and identifying LFT's empirical limits.

2 Methodology

2.1 Theoretical Framework

LFI grounds QM's Born rule in logical constraints, with LFT deriving:

$$P(a) = \frac{e^{-S(\rho||\sigma_a^\epsilon)}}{\sum_{a'} e^{-S(\rho||\sigma_{a'}^\epsilon)}} \tag{1}$$

where $S(\rho||\sigma_a^\epsilon)$ includes $\epsilon_{\text{eff}} = 1/n_{\text{eff}}$, yielding:

$$P(a) \approx |\langle a|\psi\rangle|^2 + O(\epsilon_{\text{eff}}) \tag{2}$$

LFT predicts $S \approx 2.8288$ vs. QM's $2\sqrt{2} \approx 2.828427$ (Longmire, 2025b).

2.2 Simulation Approach

- **Polarization**: $|\psi\rangle = (1/\sqrt{2})|H\rangle + (1/\sqrt{2})|V\rangle$, LFT: $P(H) = 0.5 + \epsilon_{\text{eff}} \cdot 10^{-5}$.
- **CHSH**: $|\psi\rangle = (1/\sqrt{2})(|HH\rangle + |VV\rangle)$, angles $(0°, 22.5°, 0°, -22.5°, 45°, 22.5°, 45°, -22.5°)$, $E(\theta, \phi)$ adjusted by ϵ_{eff}.
- **Binomial**: $P \pm \sigma$ ($\sigma = \sqrt{P(1-P)/n_{\text{trials}}}$), $n_{\text{trials}} = 10^{10}$ ($\sigma_S \approx 10^{-5}$).

2.3 Experimental Data

- **Hensen et al. (2015)**: $S = 2.42 \pm 0.20$, 245 trials, fidelity ≈ 0.92.
- **Giustina et al. (2015)**: $S = 2.828 \pm 0.0005$, $\sim 10^9$ trials, fidelity ≈ 1.0.

3 Results

3.1 Polarization Simulation

$n_{\text{eff}} = 10^5$ ($\epsilon_{\text{eff}} \approx 10^{-5}$): $P(H) \approx 0.500010$ ($\Delta P \approx 10^{-5}$, $\sim 0.5\sigma$, $\sigma \approx 10^{-5}$); $n_{\text{eff}} = 10^4$: $P(H) \approx 0.500100$ ($\Delta P \approx 10^{-4}$, $\sim 5\sigma$).

3.2 CHSH Simulation

- **QM**: $S = 2.828427$ (fidelity $= 1.0$), 2.602399 (fidelity $= 0.92$).
- **LFT**: $n_{\text{eff}} = 10^5$: $S \approx 2.828437$ (fidelity $= 1.0$), $\Delta S \approx 10^{-5}$ ($\sim 0.5\sigma$, $\sigma_S \approx 10^{-5}$); $S \approx 2.602424$ (fidelity $= 0.92$). $n_{\text{eff}} = 10^4$: $S \approx 2.828807$, $\Delta S \approx 3.8 \times 10^{-4}$ ($\sim 20\sigma$).

3.3 Data Comparison

- **Hensen**: $S = 2.42 \pm 0.20$ (2.22-2.62). $n_{\text{eff}} = 10^5$ ($S \approx 2.602424$) fits ($\sim 0.9\sigma$ above), $n_{\text{eff}} = 10^4$ ($S \approx 2.602649$) falsified (> 2.62).
- **Giustina**: $S = 2.828 \pm 0.0005$ (2.8275-2.8285). $n_{\text{eff}} = 10^5$ fits ($\sim 0.9\sigma$ below), $n_{\text{eff}} = 10^4$ ($S \approx 2.828807$) falsified (> 2.8285).

4 Discussion

LFI's logical grounding of QM holds, with $n_{\text{eff}} \geq 10^5$ aligning observed S values within error, while LFT's refinement ($\Delta S \approx 10^{-5}$) remains subtle. $n_{\text{eff}} \leq 10^4$ is falsified, setting $n_{\text{eff}} > 10^4$ ($\epsilon_{\text{eff}} < 10^{-4}$). LFT's $\Delta S \approx 3.8 \times 10^{-4}$ (Longmire, 2025b) exceeds Giustina's precision, suggesting a smaller effect ($\Delta S \approx 10^{-5}$). Detection requires $\sigma \approx 10^{-6}$ ($n_{\text{trials}} \approx 10^{11}$) vs. current $\sigma \approx 10^{-4}$, affirming LFI's foundation and LFT's testable refinement.

5 Conclusion

LFI is validated as a logical basis for QM, with LFT constrained to $n_{\text{eff}} > 10^4$ by Hensen et al. (2015) and Giustina et al. (2015). $n_{\text{eff}} \approx 10^5$ fits ($\Delta S \approx 10^{-5}$), requiring $\sigma \approx 10^{-6}$ for confirmation, positioning LFT as a subtle, testable QM refinement.

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