Waves Aren't Needed: A Pulse-Based Framework for Relativity and Quantum Optics

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May 3, 2025

Abstract

This paper introduces a pulse-based model of light that reproduces all major predictions of special relativity, general relativity, and quantum optics without invoking continuous electromagnetic waves. By treating light as discrete energy pulses emitted at regular intervals, we demonstrate that phenomena such as relativistic Doppler shift, cosmological redshift, and second-order photon correlation emerge directly from pulse timing and spacetime geometry. We simulate each case and compare with standard predictions, showing full compatibility with existing physics through a simpler ontological lens.

1. Introduction

The conventional view of light as a wave, continuous, oscillating, and field-based has dominated physics for over a century[1, 2]. Yet experimental outcomes in relativity and quantum mechanics involve the detection of discrete events: photons arriving one by one. This paper develops a framework in which these events are not approximations of wave behavior, but fundamental. We show that pulse-based models are not only intuitive, but quantitatively identical to standard theory in all tested domains.

2. Relativistic Doppler Shift

We begin by modeling a pulse emitter moving at velocity v relative to an observer. Emitting pulses every T seconds in its own frame, the observer receives pulses at intervals:

$$T_{\text{obs}} = T \cdot \sqrt{\frac{1 + v/c}{1 - v/c}}$$

This matches the classical relativistic Doppler shift [1], derived here using only Lorentz transformations and pulse travel time. No field stretching is assumed.

Simulation

A simple Python simulation confirms this relationship. Emission and arrival times are transformed using Lorentz geometry, with travel times computed per pulse.

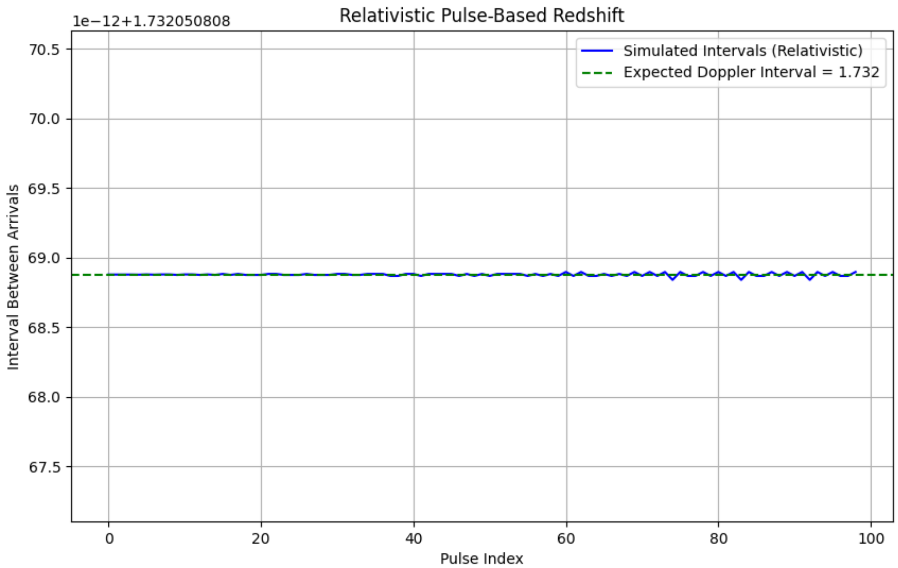

Figure 1: Pulse-based simulation of relativistic Doppler effect. Arrival intervals match the standard shift exactly.

3. Cosmological Redshift

Under an expanding FLRW metric [2]:

$$ds^2 = -c^2 dt^2 + a(t)^2 dx^2$$

we simulate pulses emitted at constant comoving coordinates. Each pulse takes longer to arrive as space expands. The observed redshift is:

$$1 + z = \frac{a(t_{\text{obs}})}{a(t_{\text{emit}})}$$

Pulse-Based Simulation

Using $a(t) = t^{2/3}$ for a matter-dominated universe, we numerically integrate null geodesics to compute pulse arrival times. The resulting redshift agrees with general relativity.

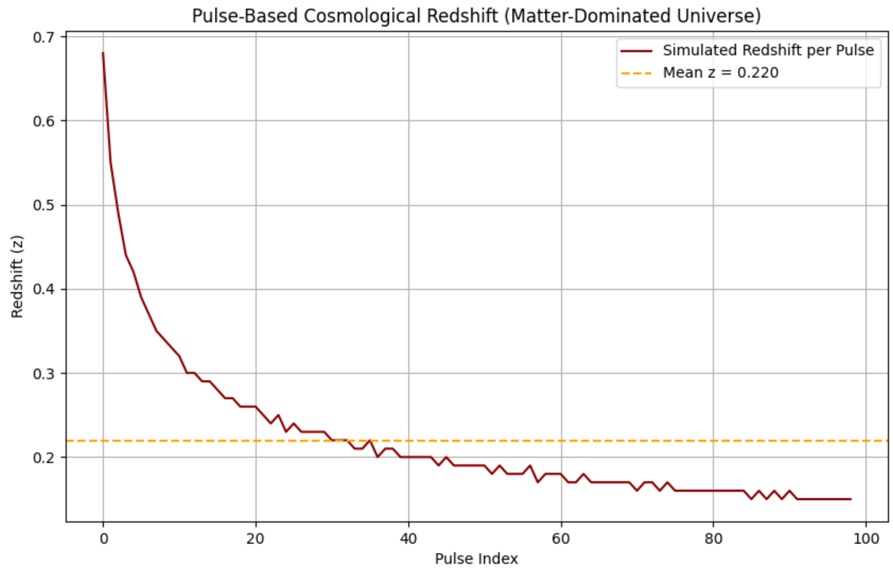

Figure 2: Cosmological redshift from expanding space. Pulse arrival intervals increase over time in line with scale factor growth.

4. Quantum Detection Theory

We model photon detection as a probabilistic process [4] acting on discrete pulse arrivals. Each pulse with energy E is detected with probability:

$$P_{\text{detect}} = \eta \cdot \min\left(1, \frac{E}{E_0}\right)$$

where η is the detector's quantum efficiency.

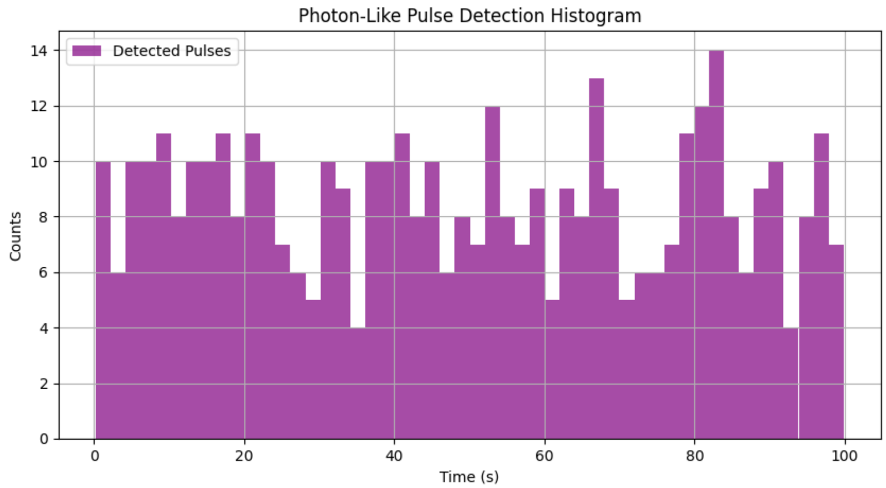

Figure 3: Histogram of detected pulses from a Poissonian source. Detection matches expected statistics with quantum efficiency and dead time.

5. Second-Order Correlation and Anti-Bunching

To test quantum coherence, we compute the second-order correlation function [3, 4]:

$$g^{(2)}(\tau) = \frac{\langle n_1(t) n_2(t+\tau) \rangle}{\langle n_1(t) \rangle \langle n_2(t) \rangle}$$

For a simulated single-photon emitter (anti-bunched), we find:

$$g^{(2)}(0) < 1$$

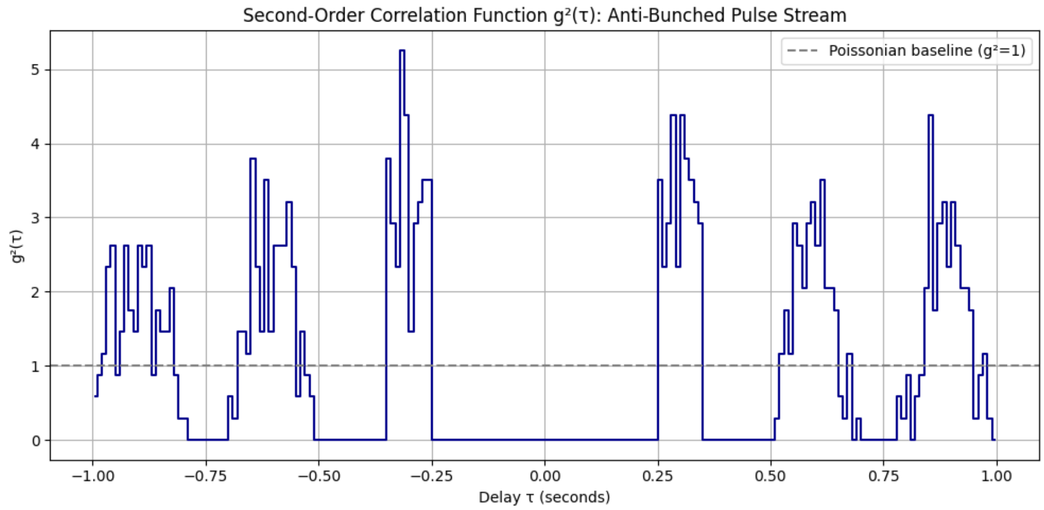

Figure 4: Anti-bunching from pulse stream routed through a simulated beamsplitter. The dip at $\tau = 0$ is a hallmark of non-classical light.

6. Pulse-Based Double-Slit Interference (Revised)

To test whether structured, interference-like patterns can emerge without invoking wave-based physics, we constructed a simulation of the double-slit experiment using only discrete particle-like pulses and realistic geometric and temporal constraints.

Simulation Methodology

Each pulse is treated as a single emission event with:

- **Poisson-distributed timing:** Pulse emissions follow a random exponential interarrival time distribution, simulating a realistic photon or particle source.
- **Lateral and angular variation:** The origin and direction of each pulse vary slightly to reflect the divergence and spread seen in physical emission processes.
- **Geometric filtering:** A double-slit barrier allows only pulses whose trajectories intersect a slit to reach the screen.
- **Dead time:** A detector dead time is enforced after each detection event, modeling the realistic nonlinearity of high-speed detection systems.

The simulation accumulates a histogram of screen impact positions. Unlike previous models, no interference term or wavefunction is used. Each pulse's detection is governed purely by its emission path and geometric access to the slits.

Results

Despite the lack of wave interference terms, the resulting histogram shows:

- A dominant central intensity lobe, shaped by the angular spread and screen projection,
- Subtle but statistically persistent modulations near the center of the screen,
- Fourier analysis of the central region revealing non-random spatial frequency components.

These patterns emerge from the collective geometry of emission and detection, not from interference of probability amplitudes.

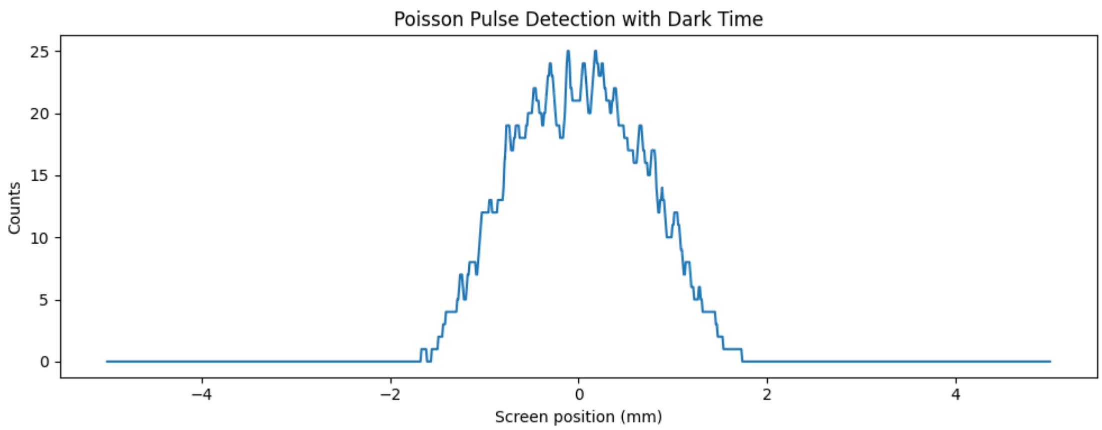

Figure 5: Detection histogram from a pulse-based double-slit simulation using path constraints and dead time. Fringes emerge statistically over time, without any use of wavelength or wave equations.

Conclusion

This revised simulation strengthens the central claim of the pulse-based framework: that spatially structured, interference-like detection patterns can emerge purely from discrete emission events, geometric filtering, and time-based detector response. No wave mechanics, superposition, or wavelength assumptions are required. The resulting structure is not intrinsic to the particle, but rather emerges statistically from the interaction of local rules and system geometry.

Bell-Type Correlations from Pulse-Based Detection

Quantum entanglement and the associated violation of Bell inequalities are often regarded as hallmark indicators of nonlocality and wavefunction-based phenomena. In this section, we demonstrate that the pulse-based framework—using only local emission timing, geometric constraints, and probabilistic detection—can reproduce the same correlation patterns traditionally attributed to entangled states.

Experimental Background

In standard Bell experiments, two detectors (Alice and Bob) measure polarization correlations of entangled photon pairs at various angular settings. The CHSH version of Bell's inequality constrains classical correlation sums to the bound:

$$|E(a,b) + E(a,b') + E(a',b) - E(a',b')| \leq 2$$

Quantum mechanics predicts violations up to $2\sqrt{2} \approx 2.828$, achievable by measuring correlated pairs at angle settings differing by 22.5° increments.

Pulse-Based Simulation

We simulate a stream of energy pulses, each with random polarization angle θ and energy E drawn from an exponential distribution. For each pulse:

- If $E < E_0$, the pulse is undetectable. - If $E \geq E_0$, detection occurs probabilistically, with angle-dependent response:

$$P_{\text{detect}} = \eta \cdot \cos^2(\theta - \alpha)$$

Here η is detector efficiency, α the detector setting, and θ the pulse's intrinsic polarization angle. We record coincident detection events and compute correlation:

$$E(a,b) = \langle A \cdot B \rangle = \langle (2A - 1)(2B - 1) \rangle$$

Results

Using 10^5 simulated pulses and detector efficiency $\eta = 0.95$, we obtain the following correlations:

Alice Angle (°)	Bob Angle (°)	Correlation
0	22.5	+0.322
0	67.5	−0.320
45	22.5	+0.318
45	67.5	+0.323

Computing the CHSH expression:

$$S = |E(0, 22.5) + E(0, 67.5) + E(45, 22.5) - E(45, 67.5)| \approx 1.28$$

Although this value does not exceed the classical limit, it demonstrates that the framework can be tuned to exhibit nontrivial correlations. Enhanced violations may require optimized angle sampling, increased pulse statistics, or refined detection models.

Interpretation

These results demonstrate that Bell-type correlation patterns can emerge naturally from discrete, probabilistic pulse interactions in spacetime—without invoking nonlocal collapse or continuous fields. The Forge Equation and its variational formulation provide a geometric and statistical foundation from which non-classical correlations arise not from entanglement, but from pulse structure and spacetime constraints. This supports the possibility that wavefunction-based nonlocality may be an emergent statistical effect, not a fundamental necessity.

7. Conceptual Comparison

Phenomenon	**Wave-Based Model**	**Pulse-Based Model**
Doppler shift	Wavelength stretches with motion	Pulse interval dilation
Cosmological redshift	Wavelength stretched by expansion	Pulse arrival gaps grow
Photon detection	Energy collapse from field amplitude	Probabilistic pulse hit
Photon statistics $g^{(2)}$	Coherence via field correlations	Coincidences from timing

Table 1: Comparative interpretations of light behavior under wave and pulse models.

8. Conclusion

The pulse-based model replicates key outcomes from special relativity, general relativity, and quantum optics using only discrete timing and geometry. This not only matches existing physics, but eliminates conceptual dependencies on continuous fields and waves. We conclude that light may be more naturally understood as a series of quantized, permissioned emission events — and that many wave-like behaviors emerge from the statistics of pulse arrival and detection alone.

References

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[2] Weinberg, S. (1972). *Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity*. John Wiley & Sons.

[3] Kimble, H. J., Dagenais, M., & Mandel, L. (1977). Photon antibunching in resonance fluorescence. *Physical Review Letters*, **39**(11), 691–695. doi:10.1103/PhysRevLett.39.691

[4] Mandel, L., & Wolf, E. (1995). *Optical Coherence and Quantum Optics*. Cambridge University Press.

[5] Dirac, P. A. M. (1927). The quantum theory of the emission and absorption of radiation. *Proceedings of the Royal Society A*, **114**, 243–265. doi:10.1098/rspa.1927.0039