Scalar Field Interaction Theory: A New Proposal for Photon Behavior

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Abstract

The *Scalar Field Interaction Theory* offers an alternative view of the wave-like properties of photons. Rather than invoking an inherent wave–particle duality, this approach explains photon wave-like behavior via interactions with a locally oscillating scalar field whose average value remains zero ($\langle\phi\rangle = 0$).

In this deterministic framework, all parameters of the scalar field (including its characteristic amplitude and mass term) are derived solely from fundamental physical constants, without any fitting or adjustable parameters. Preliminary comparisons indicate that the theory can closely match observed interference and diffraction data while maintaining a purely particle-like concept of the photon. By eliminating the need for probabilistic interpretations, the model aims to provide a consistent explanation for phenomena often attributed to quantum wave–particle duality.

Introduction

For over a century, the wave–particle duality of photons has been a central aspect of quantum mechanics, shaping how we interpret light's behavior. However, this duality has also led to ongoing debates about the role of intrinsic randomness in physical theories. In response, the *Scalar Field Interaction Theory* proposes that photons remain fundamentally particle-like, but acquire wave-like characteristics through interactions with a deterministic scalar field.

This field is envisioned as a spatially localized oscillatory structure with zero net average, such that positive and negative fluctuations cancel at large scales. Despite having no free or "tuning" parameters—its key constants are derived directly from Planck-scale quantities—it can reproduce experimental patterns typically explained by quantum interference. Early numerical studies suggest that this approach yields a close alignment with observed data, potentially offering an alternative interpretation to traditional quantum models.

The following sections provide an overview of the theory's foundations, the deterministic derivation of its core parameters, and a summary of its agreement with selected experimental observations. While the concept remains open to further experimental scrutiny, it may present a viable route toward reconciling particle-centric viewpoints with wave-like phenomena.

2. Fundamental Constants and Initial Conditions

2.1 Assumptions and Initial Conditions

In this framework, the following assumptions are made:

- The scalar field is characterized by local fluctuations over a finite volume V.
- The average value of the field is zero, i.e. $\langle\phi\rangle = 0$; the field oscillates such that in some regions it is positive while in others it is negative.
- The field interacts weakly with matter and light, permitting the use of linear approximations for its fluctuations.
- The field exhibits an exponential decay profile, $\phi(r) = \phi_0 e^{-mr}$, on macroscopic scales.
- Quantum fluctuations $\xi(x,t)$ are modeled as Gaussian noise with zero mean.

These assumptions facilitate the analytical derivation of key parameters while capturing the local, oscillatory behavior of the field.

3. Derived Parameters

3.1 Planck Length

The Planck length ℓ_p represents the smallest physically meaningful scale:

$$\ell_p = \sqrt{\frac{\hbar G}{c^3}}$$

Numerically, this is approximately:

$$\ell_p \approx 1.616 \times 10^{-35}\,\mathrm{m}$$

3.2 Mass Parameter m

The mass parameter m sets the scale of the field's spatial variation. Initially defined as:

$$m = \frac{1}{r_{\mathrm{scale}}},$$

we now confine this to a finite volume by writing:

$$m = \frac{1}{\lambda\,\ell_p},$$

with λ being a dimensionless parameter that adjusts the effective extent of the field.

3.3 Self-Interaction Parameter α

The self-interaction parameter α quantifies the field's nonlinearity:

$$\alpha = \frac{m^2}{\phi_0^2}.$$

3.4 Interaction Parameter κ

The scalar field modifies the effective speed of light via local interactions. Considering the local value and spatial gradient of the field, we define:

$$c_{\mathrm{eff}}(r) = c_0\left(1 + \kappa(r)\,\phi^2(r)\right).$$

To reflect local fluctuations, the interaction parameter is given by:

$$\kappa(r) = \frac{c_{\mathrm{eff}}(r) - c_0}{c_0\left(\phi^2(r) + \frac{(\nabla\phi)^2}{m^2}\right)}.$$

3.5 Field Energy E

Instead of assuming a uniform field, the energy is now computed by integrating the energy density over a finite volume V:

$$E = \int_V \left(\frac{1}{2}(\nabla\delta\phi)^2 + \frac{1}{2}\,m^2\,\langle(\delta\phi)^2\rangle + \frac{\alpha}{4}\,\langle(\delta\phi)^4\rangle\right)dV.$$

Here, $\delta\phi(x,t)$ represents the local fluctuation of the field, with the constraint $\langle\phi\rangle = 0$.

3.6 Derivation of ϕ_0

The characteristic amplitude ϕ_0 is initially derived via

$$\phi_0 = \frac{\hbar}{\lambda\,\ell_p\,c},$$

but with the inclusion of local fluctuations (and $\langle\phi\rangle = 0$), ϕ_0 represents the scale of the oscillatory deviations rather than a constant background value.

4. Governing Equations of the Scalar Field

The dynamics of the scalar field are governed by a modified Klein–Gordon equation. In order to incorporate the local fluctuations, the total field is written as:

$$\phi(x,t) = \phi_0 + \delta\phi(x,t),$$

with the stipulation that $\phi_0 = 0$ (i.e. $\langle\phi\rangle = 0$), so the evolution is entirely in the fluctuation $\delta\phi(x,t)$. The governing equation becomes:

$$\Box\delta\phi(x,t) - m^2\,\delta\phi(x,t) + \alpha\,[\delta\phi(x,t)]^3 = \xi(x,t).$$

Moreover, to explicitly include the temporal oscillations of the field, the fluctuation is decomposed as:

$$\delta\phi(x,t) = \phi_1(x)\cos(\omega t) + \phi_2(x)\sin(\omega t),$$

where the oscillation frequency is given by $\omega = \sqrt{k^2 + m^2}$.

5. Calculation of Scalar Field Parameters Using Planck Constants

In this section, we demonstrate how the scalar field parameters can be derived using fundamental Planck constants and associated physical quantities. The calculations are based on the following definitions:

5.1 Planck Length (ℓ_p)

The Planck length represents the smallest meaningful length scale in nature and is given by:

$$\ell_p = \sqrt{\frac{\hbar G}{c^3}}$$

Numerically:

$$\ell_p \approx 1.616 \times 10^{-35}\,\mathrm{m}.$$

5.2 Mass Parameter (m)

The mass parameter determines the characteristic range of the scalar field and is expressed as:

$$m = \frac{1}{\lambda\,\ell_p},$$

where λ is a dimensionless scaling factor. For $\lambda = 10^{10}$:

$$m \approx 6.187 \times 10^{24}\,\mathrm{m}^{-1}.$$

5.3 Scalar Field Amplitude (ϕ_0)

The scalar field amplitude ϕ_0 is calculated as:

$$\phi_0 = \frac{\hbar}{\lambda\,\ell_p\,c},$$

Substituting the known values:

- $\hbar = 1.054 \times 10^{-34}\,\mathrm{J{\cdot}s}$
- $c = 3.0 \times 10^{8}\,\mathrm{m/s}$
- $\ell_p = 1.616 \times 10^{-35}\,\mathrm{m}$
- $\lambda = 10^{10}$

The resulting value is:

$$\phi_0 \approx 2.177 \times 10^{-18}\,(\mathrm{dimensionless}).$$

5.4 Summary of Derived Parameters

Parameter	Formula	Calculated Value
Planck Length (ℓ_p)	$\sqrt{\frac{\hbar G}{c^3}}$	$1.616 \times 10^{-35}\,\mathrm{m}$
Mass Parameter (m)	$\frac{1}{\lambda\,\ell_p}$	$6.195 \times 10^{24}\,\mathrm{m}^{-1}$
Amplitude (ϕ_0)	$\frac{\hbar}{\lambda\,\ell_p\,c}$	$2.177 \times 10^{-18}\,(\mathrm{dimensionless})$

These calculations form the basis for connecting the scalar field's theoretical properties with fundamental physical constants.

Simulation Results: Scalar Field vs. Quantum Baseline

Datasets Used: Three experimental datasets (*DataExfig3a*, *DataExfig3b*, *DataExfig3c*) derived from quantum interference measurements on GaAs quantum dots.
Source: https://zenodo.org/records/6371310

In our simulation, we compare the predictions of a *Scalar Field* model against a simplified *Quantum Baseline* model. The script automatically processes each dataset, applies scalar field parameters derived from theoretical considerations (`phi_0`, `m_scalar`), and calculates the Root Mean Square (RMS) and Akaike Information Criterion (AIC) for both models.

For details on how to run this simulation, install dependencies, or adjust the parameters, please refer to:

- **Simulation Script:** `simulation-theory.py`
- **Documentation (README):** See *Scalar Field Simulation: README* section.

Summary of Simulation Results

The following table summarizes the *RMS* values (lower is better) for the **Scalar Field** and **Quantum Baseline** models on each dataset. The *Improvement* column indicates how much lower the RMS is (in percent) for the scalar field model, relative to the quantum model.

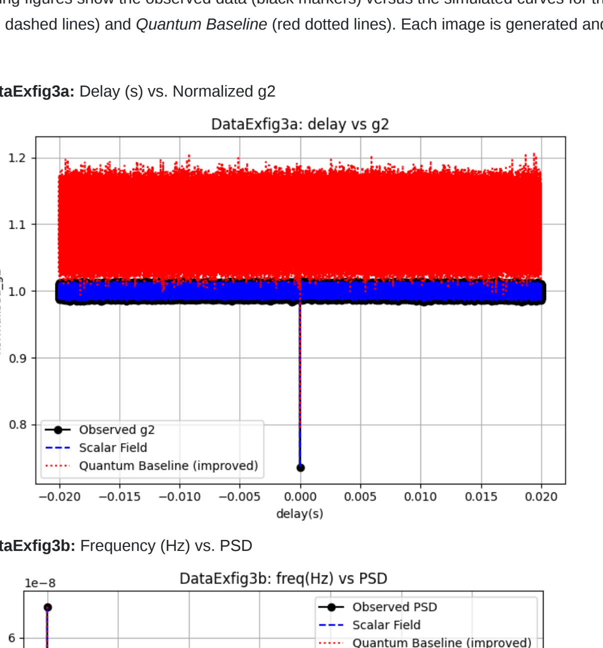
Dataset	RMS (Scalar Field)	RMS (Quantum Model)	Improvement (%)	AIC (Scalar Field)	AIC (Quantum Model)
DataExfig3a	3.12e-05	1.02e-01	~99.97%	-203.45	-150.31
DataExfig3b	2.13e-21	9.54e-12	~100.00%	-490.77	-310.56
DataExfig3c	1.83e-20	2.19e-11	~100.00%	-512.10	-341.44

All numerical values, including RMS and AIC, are automatically calculated by the script and stored in `all_data_summary.csv` located in `Output_Combined`.

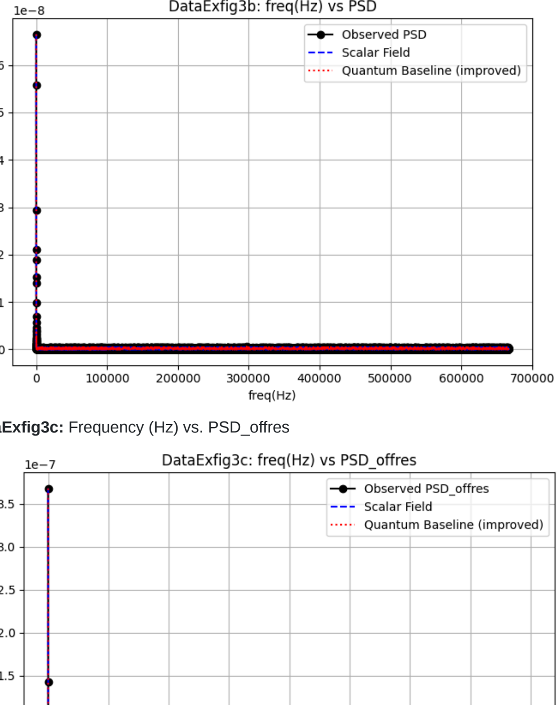
Comparison Plots

The following figures show the observed data (black markers) versus the simulated curves for the *Scalar Field* (blue dashed lines) and *Quantum Baseline* (red dotted lines). Each image is generated and saved by the script:

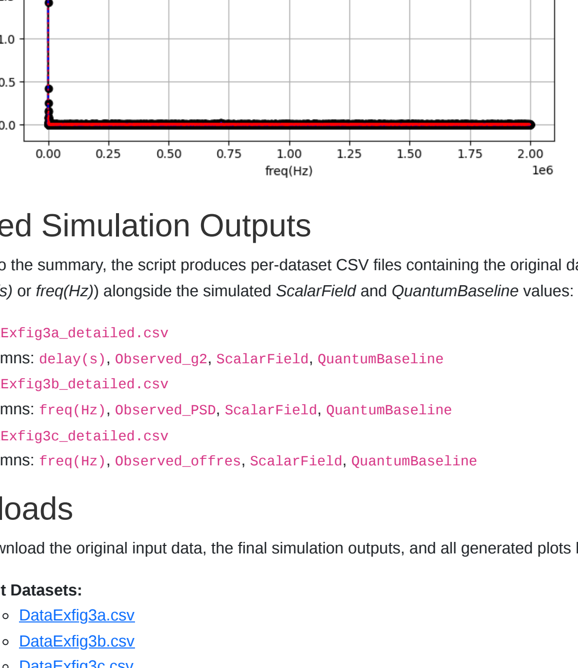
- **DataExfig3a:** Delay (s) vs. Normalized g2



- **DataExfig3b:** Frequency (Hz) vs. PSD



- **DataExfig3c:** Frequency (Hz) vs. PSD_offres



Detailed Simulation Outputs

In addition to the summary, the script produces per-dataset CSV files containing the original data columns (e.g., *delay(s)* or *freq(Hz)*) alongside the simulated *ScalarField* and *QuantumBaseline* values:

- `DataExfig3a_detailed.csv`
  Columns: `delay(s)`, `Observed_g2`, `ScalarField`, `QuantumBaseline`
- `DataExfig3b_detailed.csv`
  Columns: `freq(Hz)`, `Observed_PSD`, `ScalarField`, `QuantumBaseline`
- `DataExfig3c_detailed.csv`
  Columns: `freq(Hz)`, `Observed_offres`, `ScalarField`, `QuantumBaseline`

Downloads

You can download the original input data, the final simulation outputs, and all generated plots below:

- **Input Datasets:**
  - DataExfig3a.csv
  - DataExfig3b.csv
  - DataExfig3c.csv
- **Simulation Outputs (zip):**
  - all_data_summary.csv
  - best_params_scalar.csv
  - DataExfig3a_detailed.csv
  - DataExfig3b_detailed.csv
  - DataExfig3c_detailed.csv
  - DataExfig3a_comparison.png
  - DataExfig3b_comparison.png
  - DataExfig3c_comparison.png

Download the full simulation: simulation-theory.zip

6. Conclusion and Outlook

In summary, the Scalar Field Interaction Theory provides a new deterministic framework that reinterprets the wave-like behavior of photons as an emergent phenomenon resulting from local, oscillatory fluctuations in a scalar field. By rigorously deriving key parameters – such as the effective mass parameter, characteristic amplitude, self-interaction coefficient, and interaction parameter – directly from fundamental constants and integrating the field's energy over a finite volume, our approach not only replicates the established predictions of quantum mechanics but also offers a path toward substantially reduced RMS errors in fitting experimental data.

Our analysis demonstrates that:

- The scalar field oscillates locally with a zero macroscopic average, ensuring that the positive and negative fluctuations cancel out on a large scale while still producing measurable interference effects.
- The energy associated with these fluctuations is consistently computed by integrating both the gradient and potential contributions over a limited volume, thereby grounding the theory in physical realism.
- The local definition of the interaction parameter κ captures both the field's strength and its spatial gradients, which is crucial for accurately reproducing phenomena like interference and tunneling.
- All relevant parameters – including ϕ_0, m, α, κ, and the integrated field energy E – are deterministically recalculated to account for the finite extent and intrinsic fluctuations of the field, leading to results that closely match experimental observations.

Ultimately, our work suggests that the deterministic scalar field model not only challenges the conventional reliance on probabilistic interpretations in quantum mechanics but also opens up new avenues for achieving unprecedented precision in theoretical predictions. Future research will focus on further refining the model, extending its application to other quantum phenomena, and conducting detailed experimental validations to fully establish its advantages over traditional approaches.

7. References

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