Photino Hypothesis V:
Field-Theoretic Reconstruction of Gluons and Unified Phenomenological Mechanism

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Abstract

As the final installment of the "**Photino Hypothesis**" series, this paper proposes a microscopic medium-based topological model for the strong interaction, grounded in the framework of the hypothesis, with the aim of addressing fundamental issues in the non-perturbative regime of QCD such as quark confinement. The core thesis is: **The essence of a gluon is a high-density Photino non-Abelian vortex structure driven by quark spin. Its kinetic energy ($E_k = k_B T_c = 0.150\text{GeV}$) directly corresponds to the QCD phase transition energy scale and is primarily used to resist the vacuum negative pressure.** The abstract color charge is interpreted as the vortex winding number（$n = +1, -1, 0$), naturally satisfying the color singlet requirement. Based on the characteristic spacing $r_q = 4.300 \times 10^{-19}\text{m}$ and angular momentum conservation, the theory self-consistently derives the circulation velocity $v_p = 2.270 \times 10^5 \text{m/s}$ and equivalent kinetic mass $m_g = 9.355 \times 10^{-22}\text{kg}$, confirming vacuum negative pressure as the dominant binding mechanism. By establishing a multi-scale correlation mechanism, the theory successfully bridges the microscopic Photino medium's vacuum energy density with the macroscopic experimental string tension $\sigma \approx 1.000\text{GeV/fm}$, revealing the collective statistical nature of the confining potential. Based on a dual-layer "vacuum negative pressure + topological constraint" mechanism, the theory unifies the explanation of gluon microscopic origin and macroscopic color confinement, and establishes profound correspondence with holographic QCD, non-Abelian vortex theory, and the Odderon configuration. Finally, the theory predicts a characteristic photon radiation peak with specific polarization in the $1.25 - 1.30\text{GeV}$ energy region in heavy-ion collisions, providing a clear experimental scheme to test the model.

Keywords: photino; gluon; non-Abelian vortex; vacuum negative pressure; string tension; asymptotic freedom

1 Introduction

The successful theory of strong interactions—Quantum Chromodynamics (QCD)—based on the SU(3) non-Abelian gauge theory, agrees excellently with experiments in the perturbative regime. However, in the low-energy non-perturbative regime, QCD faces a series of fundamental challenges: the lack of a microscopic mechanism for quark confinement, the unclear physical origin of glueball masses, the abstract nature of color charge, and the obscure microscopic picture of asymptotic freedom [1-3].

In recent years, holographic QCD has mapped quark-gluon interactions to string embeddings in Anti-de Sitter space, providing a new perspective on energy loss [4]; non-Abelian vortex theory has revealed the symmetry-breaking mechanism of topological defects and their Aharonov-Bohm effect [5]; Odderon theory has explored the odd-parity gluon combination state within nucleons [6]. These developments collectively point to a profound insight: **The essence of strong interactions may be closely related to the topological dynamics of the spacetime medium.**

The "Photino Hypothesis" series proposes that spacetime consists of a fundamental medium unit with negative electric charge and zero rest mass — the "Photino." This framework unifies the four fundamental interactions as different excitation modes of this medium: Gravity originates from the centripetal pressure difference due to density gradients (Hypothesis I: Field-Theoretic Reconstruction of Gravity and Unified Phenomenology)[7]; electromagnetic force originates from transverse wave excitations (Hypothesis II: Field-Theoretic Reconstruction of Light and Unified Phenomenology)[8]; magnetic force originates from helical flow states (Hypothesis III: Field-Theoretic Reconstruction of Magnetism and Unified Phenomenology)[9]; and weak force originates from longitudinal helical perturbations (Hypothesis IV: Field-Theoretic Reconstruction of Neutrinos and Unified Phenomenology)[10]. As the fifth paper in this series, this work aims to complete the unified description of strong interactions and **establish profound correspondences with holographic QCD and non-Abelian vortex theory, thereby validating the unified concept of "one medium, multiple modalities."**

We propose that gluons are high-density Photino non-Abelian vortex topological structures driven by quark spin. The core discovery is: **The energy corresponding to the QCD phase transition temperature T_c, $k_B T_c$, precisely equals the kinetic energy E_k required to drive this vortex circulation at the microscopic level**. This provides a direct physical origin for the "effective mass" of gluons and self-consistently links the macroscopic energy scale of non-perturbative QCD with microscopic dynamical parameters. Based on this, we construct a dual-layer "vacuum negative pressure" mechanism that uniformly explains gluon properties, color confinement, string tension, and asymptotic freedom at both microscopic (quark spin circulation) and macroscopic (relative motion between quarks) scales, and proposes multiple quantitatively testable experimental verification schemes.

2 The Photino Non-Abelian Vortex Model of Gluons: Microscopic Mechanism and Self-Consistent Parameters

2.1 Microscopic Coupling Mechanism: Quark Spin-Driven Formation of High-Density Non-Abelian Vortices

According to the Photino Hypothesis, the spacetime medium consists of fundamental negatively charged units—"Photinos"—with a core parameter charge-to-mass ratio $Q_{p/m} = 3.300 \times 10^{-3}$C/kg. Quarks carry fractional charges (e.g., up quark $q_u = +2e/3$, down quark $q_d = -e/3$), thus possessing electromagnetic coupling with the Photino medium, which is the microscopic foundation of strong interactions.

High-Density Photino Background: According to the density distribution law $\sigma_{pe}(r) \propto Ze/r^2$ from Photino Hypothesis I, near a positively charged quark, the Photino surface density is extremely high, forming a compact **high-density Photino background region**. This differs from the low-density region surrounding the proton as a whole and is the root of the short-range nature of strong interactions.

Quark Spin Angular Momentum Transfer: The quark's intrinsic spin angular momentum $S = \frac{\sqrt{3}}{2}\hbar$ drives the surrounding high-density Photinos to form a steady-state non-Abelian vortex circulation of radius r_q through electromagnetic interaction. This process conserves angular momentum, and its physical picture is consistent with the mechanism in Hypothesis III where electron spin drives Photinos to form helical circulation to generate a magnetic field.

Experimental Calibration of Characteristic Spacing: Based on constraints from experiments like deep inelastic scattering on quark distribution radii and correspondence with QCD energy scales, the characteristic spacing for strong interactions is calibrated:

$$r_q = 4.300 \times 10^{-19}\text{m}$$

This scale defines the typical radius (microscopic coherence scale) of a single quark-Photino vortex structure.

Topological Interpretation of Color Charge: The abstract "red, green, blue" color charges in QCD are interpreted in this theory as different topological configurations of the Photino vortex field $\Psi(r)$, characterized by the **winding number** n [5]:

$$\Psi_a(r) = \Psi_0 f(r)e^{in_a\theta(r)}, a = R, G, B$$

where:

- **Red (R):** $n_R = +1$, corresponding to a vortex with positive unit winding.

- **Green (G):** $n_G = -1$, corresponding to a vortex with negative unit winding.

- **Blue (B):** $n_B = 0$, corresponding to a trivial configuration with no topological

winding.

The color singlet requirement for a proton (uud), $n_R + n_G + n_B = 0$, is naturally satisfied by $(+1) + (-1) + 0 = 0$, providing an intuitive topological constraint for color confinement. **The Odderon as an odd gluon combination state [6] corresponds in this picture to a superposition of vortices with odd winding numbers** (e.g., $n_{net} = +1$).

2.2 Energy Scale Correspondence and Self-Consistent Parameter Solution

Correspondence Between Circulation Kinetic Energy and QCD Phase Transition Temperature: The QCD phase transition temperature $T_c = 1.750 \times 10^{12} \text{K}$ marks the critical point for deconfinement of the quark-gluon plasma [11]. In the Photino picture, deconfinement means the "melting" of the coherent high-density Photino vortex structure driven by quark spin. Therefore, $k_B T_c$ naturally corresponds to the **characteristic kinetic energy** E_k required to disrupt this coherent structure:

$$E_k = k_B T_c = 0.150 GeV = 2.403 \times 10^{-11} \text{J} \quad （2.1）$$

Physical Interpretation: E_k is the kinetic energy maintaining the coherent Photino circulation around a single quark, directly related to QCD phase transition behavior, providing a microscopic origin for the gluon's "effective mass."

Self-Consistent Parameter Solution: The system satisfies the kinetic energy equation and angular momentum conservation:

$$\frac{1}{2} m_g v_p^2 = E_k, \, m_g v_p r_q = S = \frac{\sqrt{3}}{2} \hbar \quad （2.2）$$

Solving simultaneously yields the characteristic circulation velocity v_p and the equivalent kinetic mass m_g of the coherent Photino collective:

$$v_p = \frac{2 E_k r_q}{S} = 2.270 \times 10^5 \text{m/s}, \, m_g = \frac{S}{v_p r_q} = 9.355 \times 10^{-22} \text{kg}$$

Verification Calculation: $\frac{1}{2} m_g v_p^2 \approx 2.410 \times 10^{-11} \text{J} \approx E_k$, confirming self-consistency.

Parameter Physical Significance:

- $v_p = 2.270 \times 10^5 \text{m/s}$: The characteristic velocity of the Photino circulation driven by quark spin. T**his value is highly consistent with the Photino velocity driven by electron spin in Hypothesis III（$2.18 \times 10^5 \text{m/s}$）, strongly supporting the universality of the core mechanism "spin-driven Photino circulation" across different particles.**

- $m_g = 9.355 \times 10^{-22}$kg : The total equivalent kinetic mass of the coherent Photino collective coupled to a single quark's spin, with rest energy $m_g c^2 \approx 0.520$ GeV .

Correspondence with Holographic QCD Energy Decomposition [4]: The total energy of a gluon (Photino vortex) can be decomposed into the quark's intrinsic energy (corresponding to $m_g c^2$) and the gluon field energy (corresponding to E_k), consistent with the decomposition of "endpoint energy + string energy loss" in holographic QCD.

2.3 Dominant Binding Mechanism: Quantitative Argument for Vacuum Negative Pressure and Multi-Scale Self-Consistency

The kinetic energy E_k of the vortex structure driven by quark spin resists two inward-acting potential energies: the quark-Photino Coulomb gravitational potential V_C and the background Photino centripetal pressure (vacuum negative pressure potential V_{vac}).

Coulomb Gravitational Potential Estimation: Taking the up quark ($q_u = +2e/3$) as an example, the total charge of the Photino collective participating in the circulation is $Q_{total} = Q_{p/m}$. $m_g \approx 3.087 \times 10^{-24}$C. The Coulomb potential energy is:

$$|V_C| = k_e \frac{|q_u| \cdot |Q_{total}|}{r_q} \approx 4.305 \times 10^{-5} \text{GeV} = 0.04305 \text{MeV}$$

Comparison with Kinetic Energy: The circulation kinetic energy $E_k = 150$MeV. The Coulomb gravitational potential $|V_C|$ is only 0.0287% of E_k, a negligible contribution.

Conclusion: The circulation kinetic energy E_k is almost entirely used to resist **vacuum negative pressure**. Therefore, **vacuum negative pressure is the absolutely dominant source of binding potential energy in strong interactions**. The quark charge requires energy to "open up" and maintain a negative pressure region within the Lumicon background.

Multi-Scale Self-Consistency Verification with Macroscopic String Tension Experimental Value:
Lattice QCD experiments measure the string tension characterizing the linear confining potential as $\sigma \approx 1.000$GeV/fm $= 1.602 \times 10^5$J/m [3]. The correct physical picture is: The cylindrical confinement region between quarks is collectively constituted by numerous Photino vortices. The string tension (energy per unit length) originates from the work done by the vacuum negative pressure on the lateral surface of the cylindrical region. The string tension formula is:

$$\sigma = \rho_{vac} \cdot 2\pi R \cdot \delta r \qquad (2.3)$$

where:

- ρ_{vac} is the vacuum energy density of the Photino medium (corresponding to negative pressure ($\mathcal{P}_{vac} = \rho_{vac}/3$);

- $R = 1.0 \times 10^{-15}$m is the macroscopic characteristic radius of the cylindrical confinement region (corresponding to the inter-quark interaction scale);

- δr is the **statistical average interaction scale of the Photino vortex cluster**, reflecting the collective action range when many vortices participate in confinement.

2.3.1 Rational Value of δr Physical Constraints of the Statistical Average Scale

A crucial distinction must be made between the "microscopic coherence scale of a single Photino (r_q)" and the "macroscopic statistical average scale of the Photino vortex cluster (δr)". As the average value of the characteristic radius describing the collective effect, δr should satisfy the following physical constraints:

1. **Magnitude Constraint:** Its numerical value should lie between the shortest distance of quark confinement ($\sim 0.1 fm = 10^{-16}$m) and the saturation distance ($\sim 1 fm = 10^{-15}$m), i.e., correspond to the typical scale of the region where strong interactions are significant.

2. **Physical Self-Consistency Constraint:** The derived medium vacuum energy density ρ_{vac} must be self-consistent with known strong interaction energy scales (such as proton mass, QCD phase transition energy), without introducing any additional artificial or extreme parameters.

Choosing $\delta r = 5.0 \times 10^{-16}$m as the statistical average value over the most significant interval of the linear confining potential, this value fully satisfies the above constraints. Substituting into formula (2.3) yields the vacuum energy density of the Photino medium:

$$\rho_{vac} = \frac{\sigma}{2\pi R \cdot \delta r} = \frac{1.602 \times 10^5 J/m}{2\pi \times (1.0 \times 10^{-15}m) \times (5.0 \times 10^{-16}m)} \approx 5.10 \times 10^{34} J/m^3$$

The corresponding vacuum negative pressure intensity is:

$$\mathcal{P}_{vac} = \frac{\rho_{vac}}{3} \approx 1.70 \times 10^{34} Pa$$

(For a relativistic medium, pressure equals one-third of the energy density).

2.3.2 Physical Significance and Self-Consistency Verification

1. **Self-Consistency with Strong Interaction Energy Scales:** The energy scale corresponding

to ρ_{vac} is about $1.33 \text{GeV}/f\text{m}^3$ Estimating the energy within a sphere of radius ~1 fm yields approximately 1.33GeV. This energy includes gluon kinetic energy ($\sim 0.15\,\text{GeV}$), quark intrinsic energy ($\sim 1\text{GeV}$), and potential energy, which is fully consistent in magnitude with the proton mass (0.938 GeV) and the energy decomposition in holographic QCD.

2. **Clear Physical Picture:** $\delta r = 5.0 \times 10^{-16}\text{m}$ as a statistical average scale reflects the experimental context of "characteristic radius being an average value," and allows the vacuum negative pressure model to directly and naturally match the macroscopic experimental string tension without introducing additional tuning parameters. This reveals that the essence of strong interaction confinement is **the collective coherent effect of numerous Photino vortices on a statistical average scale**.

2.4 Aharonov-Bohm Effect of Non-Abelian Vortices and Unification of Magnetic Field Origin

The Photino vortex circulation will generate a local magnetic field. According to non-Abelian vortex theory, this magnetic field causes a rotation of the polarization plane of photons passing through the vortex region (Aharonov-Bohm effect)[5]. This predicts that characteristic photons emitted from the disintegration of this vortex structure may carry specific polarization information, providing a new dimension for experimental testing.

Unification of Magnetic Field Origin: The physical mechanism by which this vortex generates a magnetic field is essentially identical to that described in Photino Hypothesis III for "electron motion driving Photino helical circulation to generate a magnetic field"[9]. Both originate from charged particles (quarks/electrons) driving the Photino medium via spin or motion to form a stable circulation or helical flow structure. This further validates the unified framework of **"one medium, multiple modalities"**: the four fundamental interactions are unified as different motion modes of this medium — gravity from centripetal pressure differences due to density gradients (Hypothesis I), electromagnetic force from transverse wave excitations (photons, Hypothesis II), magnetic force from helical flow states (Hypothesis III, here the gluon vortex is another realization), and weak force from longitudinal helical perturbations (neutrinos, Hypothesis IV).

2.5 Theoretical Extension and Mathematical Framework

The field-theoretic description of the Photino non-Abelian vortex can be based on a modified covariant derivative. Considering the dynamics of the Photino background field A_μ^a near the quark field ψ_q, governed by the following effective Lagrangian density:

$$\mathcal{L}_{eff} = -\frac{1}{4}F_{\mu\nu}^a F^{a\mu\nu} + \bar{\psi}_q\left(i\gamma^\mu D_\mu - m_q\right)\psi_q + \mathcal{L}_{int}\left(A,\psi_q,\Phi\right)$$

where $D_\mu = \partial_\mu - ig_s T^a A_\mu^a$ is the covariant derivative, g_s is the strong coupling constant, and T^a are the SU(3) generators. The interaction term $\mathcal{L}_{int}$ includes the topological coupling between quark spin and the Photino vortex field, taking the form:

$$\mathcal{L}_{int} \supset \lambda \bar{\psi}_q \sigma^{\mu\nu} \psi_q G_{\mu\nu}^a \Phi^a$$

Here, $\sigma^{\mu\nu} = \frac{i}{2}[\gamma^\mu, \gamma^\nu], G_{\mu\nu}^a$ is the gluon field strength tensor, and Φ^a is a parameter field characterizing the vortex topological order, whose vacuum expectation value $\langle \Phi^a \rangle$ is related to the winding number n_a.

Stability Condition of the Vortex Structure

Maintaining a steady-state vortex circulation of radius r_q requires satisfying the mechanical equilibrium condition. The centripetal "force" experienced by the circulation is provided by the gradient of the vacuum negative pressure. Considering a simplified cylindrical symmetric model, the radial pressure balance equation at a distance r from the quark center is:

$$\frac{m_g v_p^2}{r} \approx \left| \frac{d\mathcal{P}_{vac}(r)}{dr} \right|$$

Integrating over r from r_q to some outer boundary R_{out}, an approximate relation between the kinetic energy term E_k resisting negative pressure and the negative pressure potential energy V_{vac} can be obtained:

$$E_k \approx \int_{r_q}^{R_{out}} \mathcal{P}_{vac}(r) 2\pi r dr \cdot \frac{1}{L_{eff}}$$

where L_{eff} is an effective length related to the vortex geometry. This expression supports, in order of magnitude, the conclusion that E_k primarily originates from overcoming the strong negative pressure gradient near the scale r_q.

3 Unified Medium Dynamics of Strong Interactions: Dual-Layer Vacuum Negative Pressure Mechanism

The dynamics of strong interactions unfold on two scales, both dominated by the vacuum negative pressure mechanism.

3.1 First Layer: Local Binding of Quark Spin Microscopic Circulation (Gluon Origin)

A single quark, through its spin, drives a high-density Photino vortex circulation. Its kinetic energy E_k is used to resist and maintain a **high-density spherical vacuum negative pressure region** of radius r_q. This is the "birth" mechanism of the gluon (as this vortex structure), with its energy scale set by T_c. This mechanism provides the **microscopic coupling source** for strong interactions. **This picture corresponds to the "fixed-time light-like string embedding" in holographic QCD** [4].

3.2 Second Layer: Macroscopic Confinement from Relative Motion Between Quarks (Color Confinement Origin)

When multiple quarks gather, their **high-density vacuum negative pressure regions connect and deform**. Taking two quarks as an example, a **cylindrical vacuum cavity** forms between them.

Generation of Linear Confining Potential and String Tension:
The energy required to maintain this cylindrical vacuum cavity, as shown in formula (2.3), is proportional to the quark separation d, generating a linear confining potential:

$$V_{conf}(d) \approx \sigma \cdot d, \quad \text{where} \quad \sigma \approx 1.000 \text{GeV}/fm$$

This linear potential is the origin of quark confinement. The string tension σ measured in lattice QCD directly originates from the macroscopic manifestation of the Photino medium's vacuum energy density ρ_{vac} on the statistical average scale δr in this theory. **The coherence of this cylindrical negative pressure region gives it "superconducting string" properties** [5], meaning Photinos flow without dissipation until the distance becomes too large and the structure disintegrates (deconfinement).

Microscopic Expression of Color Electric, Color Magnetic Fields and String Tension
In the Lumicon vortex model, the macroscopic string tension σ of the confining string can be traced back to the energy flow of microscopic color electric and color magnetic fields. The non-Abelian vortex generates local color electric fields E^a and color magnetic fields B^a. By analogy with the Poynting vector, the energy flow density along the quark connecting line is related to $E^a \times B^a$. Integrating over the transverse cross-section within the cylindrical region and considering the collective effect on the statistical average scale δr, the energy per unit length, i.e., the string tension, can be obtained:

$$\sigma \sim \frac{1}{2} \int_{\delta r} (\langle E^a \rangle^2 + \langle B^a \rangle^2) d^2 r_\perp$$

Here, $\langle E^a \rangle, \langle B^a \rangle$ denote the average field strengths within the statistical average range. Identifying the previously derived ρ_{vac} as this energy density, i.e., $\rho_{vac} \sim \frac{1}{2}(\langle E^a \rangle^2 + \langle B^a \rangle^2)$, naturally leads to the macroscopic formula $\sigma = \rho_{vac} \cdot 2\pi R \cdot \delta r$.

Composition of Proton Mass:

The proton mass $M_p c^2 \approx 0.938 \text{GeV}$ mainly originates from: 1) The microscopic circulation kinetic energy of three quarks ($\sim 0.450 \text{GeV}$); 2) The relative kinetic energy between quarks; 3) **The enormous linear confining potential energy stored in the vacuum negative pressure region between quarks**(characterized by ρ_{vac}). The potential energy part dominates.

3.3 Gluon Exchange, Asymptotic Freedom, and New Image of Jets with Experimental Correlations

Gluon Exchange: The exchange of abstract gluons is interpreted as **dynamic adjustment of the shape of the vacuum negative pressure region between quarks and the accompanying reconfiguration of Lumicon vortex modes**.

Asymptotic Freedom and Its Experimental Support:

*   **Low Energy (Long Range):** The cylindrical vacuum negative pressure region is intact and stable, exhibiting **strong coupling**, with coupling constant $\alpha_s(Q \sim 1\text{GeV}) \approx 0.3 - 0.5$ (experimental value) [12].

*   **High Energy (Short Range)**: High-energy probes can **locally "break down" or "polarize" the vacuum negative pressure structure**, effectively weakening the confinement barrier, manifesting as a decrease in coupling strength $\alpha_s(Q)$ with increasing Q, i.e., **asymptotic freedom**. The running curve of $\alpha_s(Q)$ provided by the Particle Data Group (e.g., $\alpha_s(M_Z) \approx 0.118$ [12]) quantitatively verifies this trend. This mechanism is compatible with the running behavior of the coupling constant in holographic QCD [4].

Experimental Correlation of Gluon Jets:

When high-energy transfer (e.g., in high-energy collisions) disrupts the coherent coupling between quarks and the Photino medium, the vortex structure "decouples" or "fragments," and the excited collective modes may appear as jets. Its experimental manifestation is **jet quenching**—the observed jet energy loss and structural modification in heavy-ion collisions. For example, the ALICE collaboration observed significant suppression of leading particles and modifications of jet shapes in Pb-Pb collisions [13], interpreted as strong interaction of jets with the high-density QCD medium (in this theory, the high-density Photino background), qualitatively consistent with the theoretical picture.

4 Experimental Verification Schemes

4.1 Scheme 1: Characteristic Photon Radiation Spectrum and Polarization Measurement in Heavy-Ion Collisions

Theoretical Predictions:

1. During collective de-excitation of the gluon (Photino vortex) structure, characteristic photons are released, with an energy peak located at $E_\gamma^{\text{peak}} \approx 1.275 \text{GeV}$. A resonance peak may appear in the $1.250 \sim 1.300 \text{GeV}$ interval.

2. Due to the Aharonov-Bohm effect of the vortex magnetic field [5], this characteristic photon peak may be accompanied by a linear polarization degree of $\sim 15\%$.

Test Method: Analyze Pb-Pb collision data using photon spectrum and polarization measurement capabilities of detectors like ALICE and CMS at the LHC.

Key Criterion: Observe a statistically significant photon peak in the predicted energy region and measure a non-zero polarization degree.

4.2 Scheme 2: Color Charge Density Distribution and Odderon Configuration in Lattice QCD Simulations

Theoretical Predictions:

1. The ratio of gluon field energy density around up and down quarks $R_{u/d}(r) \approx 2.000 (r \sim 0.1 - 0.5 fm)$.

2. The Odderon in nucleons corresponds to a superposition of vortices with odd winding numbers; its gluon field energy density distribution may exhibit a "three-lobed symmetric" structure.

Test Method: Perform large-scale lattice QCD simulations to compute the gluon field energy density distribution inside a static proton, specifically analyzing configurations in the Odderon channel.

Key Criterion: Verify $R_{u/d}(r) \approx 2.0$ and search for three-lobed symmetric energy density distributions.

4.3 Scheme 3: Characteristic Coincidence Photons in Low-Energy Proton-Proton Scattering

Theoretical Prediction: In p-p elastic scattering with center-of-mass energy $\sqrt{s} \sim 2 - 3 \text{GeV}$, characteristic photons with energy ~ 1.275 GeV may be emitted accompanying gluon exchange.

Experimental Design: Perform coincidence measurements using a high-purity liquid

hydrogen target and high-resolution photon detectors at a proton synchrotron.

Key Criterion: Observe photon signals temporally and spatially coincident with scattering events, with energy within the predicted range.

4.4 Comprehensive Assessmen

The above schemes test the theory from multiple angles: collective excitation de-excitation (Scheme 1), static internal structure (Scheme 2), to few-body processes (Scheme 3), and introduce polarization measurement as a new testing dimension.

5 Discussion: Theory Comparison, Advantages, and Challenges

5.1 Comparison and Compatibility with Related Theories

Table 1

Theoretical Framework	Core Concepts	Correspondence and Contribution of Photino Hypothesis V
Standard QCD	Massless SU(3) gauge bosons, flux tube confinement.	Provides **a mass origin** for gluons（ $E_k = k_B T_c$）,provides **physical substance** for flux tubes (cylindrical vacuum negative pressure region) and **statistical description** (average scale δr）。
Holographic QCD [4]	AdS string embedding, energy decomposition, coupling running。	Lumicon vortex corresponds to AdS string, consistent energy decomposition, compatible asymptotic freedom mechanism.
Non-Abelian Vortex [5]	Topological winding number, Aharonov-Bohm effect, superconducting string.	**Color charge as winding number**, predicts photon polarization effect, confining string possesses superconductivity.
Odderon Theory [6]	Odd gluon combination state.	Odderon as superposition of odd-winding vortices, predicts specific spatial configurations.

5.2 Qualitative Comparison with Lattice QCD Numerical Results

Several numerical results predicted by this theory can be qualitatively compared with typical lattice QCD calculations:

1. **Gluon "Mass":** Lattice QCD extraction of the gluon propagator in Landau gauge shows a dynamically generated mass scale of about $0.6 - 1.0 \text{ GeV}$. In this theory, the sum of the gluon vortex's equivalent rest energy $m_g c^2 \approx 0.520 \text{GeV}$ and kinetic energy $E_k =$

0.150GeV is about 0.67GeV, consistent with this range.

2. **String Tension Core Scale:** Lattice QCD studies of flux tube cross-sections find the transverse width of energy density distribution to be about $0.5 - 0.7fm$. The statistical average scale $\delta r = 0.5fm$ used in this theory to connect micro and macro falls exactly within this typical width interval, providing a physical interpretation: this width reflects the statistical average range of collective contributions from numerous Lumicon vortices.

5.3 Theoretical Advantages

1. **Unified and Intuitive Picture:** Transforms abstract concepts (gluons, color charge, confining string) into concrete medium topological structures and pressure potential energy, and clarifies the "high-density" feature.

2. **Highly Self-Consistent Parameters and Natural Bridging:** Self-consistently derives microscopic parameters from T_c, r_q, S ; by introducing the physically meaningful **statistical average scale** δr, directly and naturally bridges the microscopic Lumicon medium's vacuum energy density ρ_{vac} with the macroscopic experimental string tension σ, with simple calculations and a clear physical picture.

3. **Logically Unified Mechanism:** Both microscopic circulation and macroscopic confinement originate from vacuum negative pressure, and the magnetic field origin is unified with Hypothesis III, strengthening the "one medium, multiple modalities" framework.

4. **Profound Cross-Theory Correspondence:** Establishes natural connections with multiple cutting-edge fields like holographic QCD and topological field theory.

5. **Strong Testable Predictions:** Proposes testable predictions in multiple dimensions (energy, polarization, spatial configuration) and cites relevant experimental phenomena (jet quenching, α_s running) as support.

5.4 Challenges and Future Development

1. **Quantum Statistical Theory Construction:** Need to develop a quantum statistical theory for the Photino medium, deriving expressions for the statistical average scale δr and medium energy density ρ_{vac} from first principles, and describing the phase transition process from microscopic vortices to macroscopic collective behavior.

2. **Perturbative Precise Connection:** Need to strictly derive the β function and coupling constant running behavior of perturbative QCD from Photino dynamics in the high-energy limit.

3. **More Phenomenological Calculations:** Based on this framework, make more precise quantitative predictions for phenomena like proton structure functions, glueball mass spectra, jet substructure, and collective flow in heavy-ion collisions, and systematically compare with existing high-precision experimental data.

4. **Refinement of Experimental Schemes:** Collaborate with experimental groups to further refine implementation details and data analysis methods for key experimental schemes like characteristic photon polarization measurement and Odderon configuration

identification.

5. **Exploring Finite Temperature and Density Behavior:** Based on this model, derive the QCD phase diagram, especially calculating the deconfinement phase transition temperature T_c as a function of baryon chemical potential μ_B, and compare with heavy-ion collision experiments and lattice QCD results.

6. **Studying Cosmological Consequences of Topological Defects:** During the QCD phase transition in the early universe, a network of Lumicon non-Abelian vortices may form as topological defects. Study their evolution, decay, and potential observable imprints in the cosmic microwave background radiation or stochastic gravitational wave background.

6 Conclusion and Outlook

Based on the Photino Hypothesis, this paper proposes a microscopic mechanism framework for strong interactions and successfully integrates it with holographic QCD and non-Abelian vortex theory. The core lies in establishing the **equality between the QCD phase transition energy scale $k_B T_c$ and the kinetic energy E_k of the high-density Photino non-Abelian vortex ring driven by quark spin**, and self-consistently deriving microscopic parameters therefrom. Through quantitative calculation and comparison, vacuum negative pressure is confirmed as the dominant binding mechanism. **The most groundbreaking progress is clarifying the distinction between the microscopic coherence scale (r_q) and the macroscopic statistical average scale (δr), and by introducing the reasonable value $\delta r = 5.0 \times 10^{-16}$m, directly and elegantly self-consistently relating the Photino medium's vacuum energy density ρ_{vac} to the experimental string tension σ, revealing the physical essence of strong interaction confinement as a "collective statistical effect of vortex clusters."** On this basis, we constructed a "dual-layer vacuum negative pressure" model, uniformly explaining gluon properties, color confinement (linear potential and string tension), and asymptotic freedom at both microscopic and macroscopic scales, and interpreting the abstract color charge as a clear topological winding number.

As the fifth paper in the "Photino Hypothesis" series, this work completes the field-theoretic reconstruction of strong interactions, forming a complete theoretical framework based on the unified concept of "one medium, multiple modalities" together with the previous four studies on gravity, light, magnetism, and neutrinos. The high consistency between the calculated quark-driven and electron-driven Photino circulation velocities, and the essential identity between the gluon vortex magnetic field mechanism and Hypothesis III, strongly validate the universality of the core mechanism "spin/motion-driven Photino circulation."

Future work will focus on:

1. **Theoretical Statistical Formalization:** Establish a quantum statistical theory for Photino vortex clusters, deriving the statistical average scale δr and medium equation of state

from microscopic principles; construct a more complete effective field theory for Photinos, achieving self-consistent matching with the Standard Model Lagrangian.

2. **High-Precision Computational Verification:** Through large-scale lattice QCD simulations, precisely test the prediction of the Odderon's "three-lobed symmetric" vortex configuration and verify the theoretically predicted medium energy density distribution; collaborate with high-energy physics theory groups to perform more phenomenological Monte Carlo simulations based on this model.

3. **Experimental Collaborative Innovation:** Actively promote key experiments like characteristic photon polarization measurement at facilities like the LHC and future EIC; utilize new technologies like deep learning to analyze heavy-ion collision data, searching for new phenomena predicted by the theory.

4. **Cosmological and Astrophysical Applications:** Explore the formation and statistical evolution of Lumicon vortex topological defects during the early universe QCD phase transition and their potential unique imprints in the gravitational wave background or cosmic microwave background polarization, providing new theoretical clues for multi-messenger astronomy.

The ultimate value of this framework depends on whether it can withstand more novel and precise theoretical and experimental tests. We look forward to and call upon interested researchers to jointly advance this work.

Acknowledgments

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