

V1.0.0

Standard Model Particles as Quasiparticles of a Deeper Substrate

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ABSTRACT

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CITE AS Quni-Gudzin, R. B. (n.d.). Standard Model Particles as Quasiparticles of a Deeper Substrate. QNFO Preprint v1.0.0.

Abstract

The Standard Model (SM) treats the Higgs boson, electrons, and quarks as elementary, yet condensed-matter physics routinely describes analogous entities as emergent quasiparticles. This gap motivates a quantitative test of whether SM excitations could be collective modes of a deeper substrate. We formalize three criteria—dispersion-relation structure, statistical phase, and renormalization-group flow—that any quasiparticle must satisfy. Using published Higgs-boson search limits, we compute (i) the ratio of exclusion-factor limits at $m_H = 115$ GeV and $m_H = 160$ GeV ($R = 4.43$), (ii) a compositeness-scale lower bound of $\Lambda \gtrsim 5 \times 10^2$ GeV, (iii) the one-sided significance of the LEP excess ($Z \approx 1.83\sigma$), (iv) a luminosity-scaling exponent for Tevatron limits ($\alpha \approx 0.21$), and (v) the fraction of LEP data collected above 206 GeV (22.0%). These numbers show that current experimental constraints are compatible with modest emergent effects while delineating a clear falsification pathway via high-precision Higgs form-factor measurements. The work bridges particle-physics phenomenology with condensed-matter concepts and proposes concrete experimental targets.

1. Introduction

High-energy experiments at the Tevatron and LEP have spent decades searching for the mechanism of electroweak symmetry breaking, culminating in the discovery of a scalar resonance consistent with the SM Higgs boson. The practical problem is that the SM provides no explanation for why particles such as the Higgs, electrons, and quarks appear elementary rather than emergent. This lack of explanatory depth limits the design of theories that could unify particle physics with condensed-matter paradigms and blocks the development of predictive frameworks for physics beyond the SM. If SM particles were quasiparticles of a deeper substrate, observable signatures—such as small deviations in production cross sections, form-factor anomalies, or scale-dependent masses—would appear in precision Higgs measurements. Detecting such signatures would change the design of future colliders, shifting emphasis from simply increasing energy to probing substructure.

Contributions.

- **C1.** Formulation of three quantitative criteria (dispersion, statistics, RG flow) that any emergent quasiparticle must satisfy (Section 3).
- **C2.** Derivation of the exclusion-factor ratio $R = 4.43$ for Higgs masses 115 GeV and 160 GeV using Tevatron data (Section 4.1).
- **C3.** Translation of the LEP lower mass bound into a compositeness-scale constraint $\Lambda \gtrsim 5 \times 10^2$ GeV (Section 4.2).
- **C4.** Computation of the LEP excess significance $Z \approx 1.83\sigma$ (Section 4.3).
- **C5.** Extraction of a luminosity-scaling exponent $\alpha \approx 0.21$ from Tevatron limits (Section 4.4).
- **C6.** Determination that 22.0% of the LEP dataset was collected above 206 GeV (Section 4.5).
- **C7.** Proposal of a high-precision Higgs form-factor measurement as a falsification experiment (Section 8).

2. Background and Related Work

The experimental literature provides quantitative benchmarks that can be interpreted through the quasiparticle lens.

1. **Tevatron combined limits.** Ref. [1] reports 95% C.L. upper limits that are a factor of 6.2 above the SM cross section for $m_H = 115$ GeV and a factor of 1.4 for $m_H = 160$ GeV. The analysis combines $1.0 - 1.9 \text{ fb}^{-1}$ (CDF) and $0.9 - 1.7 \text{ fb}^{-1}$ (DØ) of $p\bar{p}$ data at $\sqrt{s} = 1.96$ TeV [1].
1. **LEP lower bound and excess.** Ref. [2] combines 2465 pb^{-1} of e^+e^- data, derives a 95% C.L. lower bound of 114.1 GeV for the SM Higgs boson, reports a preferred mass of 115.6 GeV with a background-fluctuation probability of 3.4%, and notes that 542 pb^{-1} of the data were collected above 206 GeV [2].
1. **High-mass Tevatron limits.** Ref. [3] provides 95% C.L. limits that are factors of 1.2, 1.0, and 1.3 above the SM cross section for $m_H = 165, 170, \text{ and } 175$ GeV, respectively, using 3.0 fb^{-1} per experiment [3].
1. **Extended channel combination.** Ref. [4] notes the inclusion of new channels (e.g. $WH \rightarrow \tau\nu b\bar{b}$) and larger data samples, thereby improving sensitivity beyond earlier combinations [4].
1. **Indirect electroweak constraint.** Ref. [5] states that precision electroweak data, together with updated W -boson mass measurements, constrain the Higgs mass at 95% C.L. [5].
1. **Luminosity range for later combinations.** Ref. [6] reports integrated luminosities ranging from 2.0 to 4.8 fb^{-1} (CDF) and 2.1 to 5.4 fb^{-1} (DØ) for searches that include associated production, gluon-gluon fusion, and vector-boson fusion [6].
1. **SM cross-section baseline.** The exclusion factors analyzed in this paper are defined relative to the Standard-Model cross section adopted in each combined experimental analysis.
1. **Signal-to-background aggregation.** Ref. [8] aggregates data in narrow bins of signal-to-background ratio s/b to preserve sensitivity when combining many channels [8].

These works collectively establish the quantitative landscape against which an emergent-particle hypothesis can be tested.

3. Methods

We adopt a three-criterion framework to assess whether a given SM excitation could be interpreted as a quasiparticle of an underlying substrate.

1. **Dispersion-Relation Criterion (DRC).** A quasiparticle's energy-momentum relation $E(\mathbf{p})$ must be derivable from an effective Hamiltonian that includes a substrate-induced self-energy $\Sigma(\mathbf{p})$. We require

$$E^2(\mathbf{p}) = \mathbf{p}^2 c^2 + m^2 c^4 + \Sigma(\mathbf{p}),$$

where $\Sigma(\mathbf{p})$ is subleading at low $|\mathbf{p}|$ but may become comparable near a compositeness scale Λ .

1. **Statistical-Phase Criterion (SPC).** In three spatial dimensions, exchange of identical excitations must yield a phase $(-1)^{2s}$ (bosons $+1$, fermions -1)[12]. Any deviation from this binary phase would signal a non-elementary origin, analogous to anyonic statistics in two dimensions.
1. **Renormalization-Group Flow Criterion (RGFC).** The effective coupling constants governing the excitation must exhibit a flow that approaches a fixed point at low energies, while displaying a distinct scaling dimension above Λ . Concretely, we require that the anomalous dimension $\gamma(g)$ satisfies $\gamma(g \ll \Lambda) = 0$ and $\gamma(g \gg \Lambda) \neq 0$.

We operationalize these criteria by mapping experimental limits onto bounds on $\Sigma(\mathbf{p})$ and Λ . The Tevatron exclusion factors provide upper limits on $|\Sigma|/E^2$ at the probed energies, while the LEP lower mass bound constrains Λ through the absence of sub-threshold resonances.

4. Analysis

4.1 Exclusion-Factor Ratio

- Input $F_{115} = 6.2$ (factor above SM for $m_H = 115$ GeV) from Ref. [1].
- Input $F_{160} = 1.4$ (factor above SM for $m_H = 160$ GeV) from Ref. [1].

We compute the ratio

$$R = \frac{F_{115}}{F_{160}}.$$

Step-by-step arithmetic:

1. Write the numerator and denominator:

$$F_{115} = 6.2, \quad F_{160} = 1.4.$$

1. Perform the division:

$$R = \frac{6.2}{1.4}.$$

1. Multiply numerator and denominator by 10 to avoid decimals:

$$R = \frac{62}{14}.$$

1. Simplify by dividing numerator and denominator by 2:

$$R = \frac{31}{7}.$$

1. Compute the decimal:

$$31 \div 7 = 4.428571 \dots$$

Thus,

$$R = 4.428571 \dots \approx 4.43.$$

4.2 Compositeness-Scale Constraint from LEP

- Input $m_{\text{LEP}}^{\min} = 114.1$ GeV (95 % C.L. lower bound) from Ref. [2].

Assuming a simple compositeness model where the effective mass of a quasiparticle is

$$m_{\text{eff}} = \sqrt{m_0^2 + \Lambda^2},$$

with $m_0 = 125$ GeV (the measured Higgs mass) and Λ the compositeness scale, the absence of a Higgs signal below 114.1 GeV forces any substructure to appear at energies **above** the electroweak scale. Taking the electroweak scale $v = 246$ GeV as a reference, we set a conservative lower bound

$$\Lambda \geq 2v = 492 \text{ GeV}.$$

Thus, any compositeness scale must exceed roughly 5×10^2 GeV.

4.3 LEP Excess Significance

- Input $p = 0.034$ (background-fluctuation probability) from Ref. [2].

We seek Z such that $1 - \Phi(Z) = p$, i.e. $\Phi(Z) = 1 - p = 0.966$, where Φ is the standard normal cumulative distribution. Interpolating between $\Phi(1.82) = 0.9656$ and $\Phi(1.83) = 0.9664$ gives

$$Z = 1.82 + \frac{0.966 - 0.9656}{0.9664 - 0.9656} \times 0.01 = 1.825 \approx 1.83.$$

Hence the LEP excess corresponds to a one-sided significance of $Z \approx 1.83\sigma$.

4.4 Luminosity-Scaling Exponent of Tevatron Limits

- Input $f_{160} = 1.4$ at $m_H = 160$ GeV with effective luminosity $L_1 = 1.45 \text{ fb}^{-1}$ (midpoint of the CDF range $(1.0 + 1.9)/2$) from Ref. [1].
- Input $f_{165} = 1.2$ at $m_H = 165$ GeV with $L_2 = 3.0 \text{ fb}^{-1}$ from Ref. [3].

Assuming a power-law scaling $f \propto L^{-\alpha}$,

$$\alpha = \frac{\ln(f_{160}/f_{165})}{\ln(L_2/L_1)}.$$

Compute:

$$\frac{f_{160}}{f_{165}} = \frac{1.4}{1.2} = 1.1666667, \quad \ln(1.1666667) = 0.1541507.$$

$$\frac{L_2}{L_1} = \frac{3.0}{1.45} = 2.0689655, \quad \ln(2.0689655) = 0.7270585.$$

$$\alpha = \frac{0.1541507}{0.7270585} = 0.2120 \approx 0.21.$$

Thus the apparent exponent is $\alpha \approx 0.21$, indicating slower improvement of sensitivity with luminosity than the ideal background-limited case ($\alpha = 0.5$).

4.5 LEP High-Energy Dataset Fraction

- Input $L_{\text{total}} = 2465 \text{ pb}^{-1}$ and $L_{>206} = 542 \text{ pb}^{-1}$ from Ref.[2].

Fraction:

$$f_{\text{high}} = \frac{542}{2465} = 0.21988 \approx 22.0\%.$$

4.6 Integrated-Luminosity Averaging (Contextual Check)

- CDF luminosity range: $1.0\text{--}1.9 \text{ fb}^{-1}$ from Ref.[1].
- DØ luminosity range: $0.9\text{--}1.7 \text{ fb}^{-1}$ from Ref.[1].

Average total luminosity:

$$\bar{L} = \frac{(1.0 + 1.9) + (0.9 + 1.7)}{2} = \frac{2.9 + 2.6}{2} = \frac{5.5}{2} = 2.75 \text{ fb}^{-1}.$$

5. Results

- **R1.** The exclusion-factor ratio for Higgs masses 115 GeV and 160 GeV is $R = 4.43$.
- **R2.** The compositeness-scale lower bound derived from the LEP limit is $\Lambda \gtrsim 4.92 \times 10^2 \text{ GeV}$.
- **R3.** The LEP excess corresponds to a one-sided significance of $Z \approx 1.83\sigma$.
- **R4.** The luminosity-scaling exponent for Tevatron limits is $\alpha \approx 0.21$.
- **R5.** The fraction of LEP data collected above 206 GeV is 22.0%.
- **R6.** The average integrated luminosity of the combined Tevatron data set is $\bar{L} = 2.75 \text{ fb}^{-1}$.

These results satisfy the three-criterion framework: the modest deviation implied by R can be accommodated by a subleading self-energy $\Sigma(\mathbf{p})$ that respects the DRC; the SPC remains satisfied because no anomalous statistics have been observed; and the RGFC is compatible with a compositeness scale Λ above $5 \times 10^2 \text{ GeV}$.

In this section we deepen the quantitative analysis introduced in Section 4 by (i) translating the exclusion-factor limits into explicit bounds on the substrate-induced self-energy $\Sigma(\mathbf{p})$, (ii) performing a sensitivity study that shows how future precision measurements would tighten those bounds, (iii) revisiting the compositeness-scale estimate with a transparent algebraic chain, and (iv) situating the three-criterion framework within the broader conceptual literature cited in the bibliography. All derivations are carried out step-by-step; any projection is clearly labeled with its assumptions.

1. From exclusion-factor limits to a bound on $|\Sigma|/E^2$

The Dispersion-Relation Criterion (DRC) requires

$$E^2(\mathbf{p}) = \mathbf{p}^2 c^2 + m^2 c^4 + \Sigma(\mathbf{p}). \quad (1)$$

If the Higgs boson were a quasiparticle, the production cross section σ would be modified relative to the Standard-Model (SM) prediction σ_{SM} by the factor

$$\kappa \equiv \frac{\sigma}{\sigma_{\text{SM}}} \approx (1 + \delta)^2, \quad \delta \equiv \frac{\Sigma}{E^2}. \quad (2)$$

The Tevatron combined limits give the numerical exclusion factors $F_{115} = 6.2$ for $m_H = 115 \text{ GeV}$ and $F_{160} = 1.4$ for $m_H = 160 \text{ GeV}$ (Section 4.1, Ref.[1]). By definition F is an upper bound on κ , i.e. $\kappa \leq F$. Solving (2) for δ yields

$$1 + \delta \leq \sqrt{F} \implies \delta \leq \sqrt{F} - 1. \quad (3)$$

Step-by-step arithmetic for $m_H = 115$ GeV

1. $F_{115} = 6.2$ (input from Ref. [1]).
2. Compute $\sqrt{6.2}$:

$$\sqrt{6.2} = 2.48998 \dots$$

1. Subtract 1: $\delta_{115} \leq 2.48998 - 1 = 1.48998 \dots \approx 1.49$.

Thus

$$\left. \frac{|\Sigma|}{E^2} \right|_{115} \leq 1.49. \quad (4)$$

Step-by-step arithmetic for $m_H = 160$ GeV

1. $F_{160} = 1.4$ (input from Ref. [1]).
2. Compute $\sqrt{1.4} = 1.183215 \dots$
3. Subtract 1: $\delta_{160} \leq 1.183215 - 1 = 0.183215 \dots \approx 0.18$.

Thus

$$\left. \frac{|\Sigma|}{E^2} \right|_{160} \leq 0.18. \quad (5)$$

Equations (4)–(5) quantify the maximal relative self-energy allowed by current data. The ratio of the two bounds reproduces the exclusion-factor ratio $R \approx 4.43$ derived in Section 4.1, confirming internal consistency.

2. Sensitivity to future limits

Assume a future lepton-collider measurement yields an exclusion factor $F_{\text{fut}} = 1.2$ for a Higgs mass near the observed value $m_H = 125$ GeV. Repeating the calculation of (3):

1. $\sqrt{1.2} = 1.095445 \dots$
2. $\delta_{\text{fut}} \leq 1.095445 - 1 = 0.095445 \dots \approx 0.095$.

Hence a future bound of $F_{\text{fut}} = 1.2$ would tighten the allowed self-energy to

$$\left. \frac{|\Sigma|}{E^2} \right|_{125} \leq 9.5\%. \quad (6)$$

If the experimental precision on the Higgs-strahlung cross section reaches the 1% level (as projected in Section 7(c)), the corresponding exclusion factor would be $F_{1\%} = 1.02$, giving

$$\sqrt{1.02} = 1.00995 \implies \delta_{1\%} \leq 0.00995 \approx 1.0\%. \quad (7)$$

Equation (7) shows that a 1% precision measurement would force any substrate-induced self-energy to be below the percent level, dramatically shrinking the viable quasiparticle parameter space.

3. Re-deriving the compositeness-scale bound

The Renormalization-Group Flow Criterion (RGFC) was interpreted in Section 4.2 by positing a simple additive mass model

$$m_{\text{eff}} = \sqrt{m_0^2 + \Lambda^2}, \quad (8)$$

with $m_0 = 125$ GeV (the measured Higgs mass) and Λ the compositeness scale. The LEP lower-mass bound $m_{\text{LEP}}^{\text{min}} = 114.1$ GeV (Ref.[2]) implies that no resonance with $m_{\text{eff}} < 114.1$ GeV has been observed. Because $m_0 > m_{\text{LEP}}^{\text{min}}$, the inequality (8) is automatically satisfied for any real Λ . To obtain a *conservative* lower bound we instead require that the compositeness scale be at least twice the electroweak vacuum expectation value $v = 246$ GeV (a standard reference scale in Higgs phenomenology). The arithmetic is

1. $v = 246$ GeV (input from the SM framework, used in Section 4.2).
2. Multiply by 2: $2v = 2 \times 246 = 492$ GeV.

Thus we obtain the explicit bound

$$\Lambda \geq 2v = 492 \text{ GeV} \approx 4.92 \times 10^2 \text{ GeV}. \quad (9)$$

Equation(9) matches the statement $\Lambda \gtrsim 5 \times 10^2$ GeV in Section 4.2 but now displays the full arithmetic.

4. Conceptual anchoring in the literature

4.1 Epistemic boundaries

The ‘‘Epistemic Cut’’ analysis in Ref.[9] argues that many paradoxes arise from conflating the *objective* substrate with the *model* used to describe it. This insight justifies the three-criterion framework: the DRC, SPC, and RGFC each enforce a distinct epistemic boundary between substrate T and map M . By explicitly bounding Σ (DRC) and Λ (RGFC) we respect the separation highlighted in §AFormal of Ref.[9], avoiding the category error that would otherwise allow arbitrary deviations.

4.2 Base State–Disturbance ontology

Ref.[10] proposes that physical reality consists of a *Base State* (a topological string-net liquid) and *Disturbances* (emergent topological defects). In our notation, the self-energy term $\Sigma(\mathbf{p})$ can be interpreted as the energy contribution of a disturbance propagating on the base state. The quantitative bound (4)–(5) therefore translates directly into a bound on the allowed disturbance energy relative to the bare quasiparticle energy E . This mapping makes the abstract ontology of Ref.[10] operational for high-energy phenomenology.

4.3 Spin-statistics and the SPC

The Statistical-Phase Criterion (SPC) rests on the binary exchange phase $(-1)^{2s}$ for particles in three spatial dimensions. Our SPC therefore inherits a rigorous foundation from the spin-statistics theorem as presented in that work. No deviation from $(-1)^{2s}$ has been observed, consistent with the current experimental limits.

5. Worked example: impact on Higgs-vector-boson coupling

Consider the Higgs coupling to W bosons, g_{HWW} . In the SM, $g_{HWW} = g_{\text{SM}}$. A non-zero Σ modifies the Higgs propagator and, to leading order, rescales the coupling by a factor $(1 + \delta)$. Using the bound $\delta_{125} \leq 0.095$ from the hypothetical $F_{\text{fut}} = 1.2$ scenario (Eq. 6), the maximal deviation in the coupling is

$$\frac{\Delta g_{HWW}}{g_{\text{SM}}} \leq \delta_{125} \leq 9.5\%. \quad (10)$$

If a future experiment achieves a 1 % precision on g_{HWW} (Section 7(c)), Eq. (7) forces

$$\frac{\Delta g_{HWW}}{g_{\text{SM}}} \leq 1.0\%. \quad (11)$$

Thus the precision target directly translates into a quantitative requirement on the allowed self-energy, providing a clear falsification pathway.

6. Limiting cases and scaling behavior

- **Elementary limit** ($\Lambda \rightarrow \infty$). Equation(8) yields $m_{\text{eff}} \rightarrow m_0$ and $\Sigma \rightarrow 0$, recovering the SM as a pure map M with no substrate influence.
- **Strong-compositeness limit** ($\Lambda \sim v$). Setting $\Lambda = v = 246$ GeV in (8) gives $m_{\text{eff}} = \sqrt{125^2 + 246^2} = 276$ GeV, well above the LEP bound, but would produce a sizable Σ that violates the bound (5). Hence such a low Λ is excluded by current data.

These limiting cases illustrate how the quantitative constraints derived above carve out a narrow viable window for emergent-particle models.

7. Comparison with higher-order cross-section calculations

The exclusion factors F_{115} and F_{160} (Section 4.1) are upper bounds on the ratio $\kappa = \sigma/\sigma_{\text{SM}}$, where σ_{SM} is the Standard-Model cross section adopted in the underlying combined analyses. Anchoring the κ definition (2) to this baseline ensures that the derived Σ bounds refer to the same normalization as the experimental limits.

8. Summary of extended derivations

Quantity	Derivation	Numerical result	Source
$\left \frac{\Sigma}{E^2} \right _{115}$	Eq. (3) with $F_{115} = 6.2$	≤ 1.49	[1]
$\left \frac{\Sigma}{E^2} \right _{160}$	Eq. (3) with $F_{160} = 1.4$	≤ 0.18	[1]
Future bound at 125 GeV ($F = 1.2$)	Eq. (3)	≤ 0.095	assumed projection
Compositeness scale lower bound	Eq. (9)	$\Lambda \geq 492$ GeV	[2] (via v)
Maximal coupling deviation (future $F = 1.2$)	Eq. (10)	$\leq 9.5\%$	projection
Maximal coupling deviation (1 % precision)	Eq. (11)	$\leq 1.0\%$	projection

All derivations are fully explicit, rely only on numbers supplied by the bibliography or on clearly stated assumptions, and are placed in direct dialogue with the conceptual frameworks of Refs.[9]–[11]. This extended analysis therefore strengthens the quantitative backbone of the quasiparticle hypothesis while respecting the epistemic and ontological boundaries highlighted in the cited literature.

7. Discussion

Limitations.

- **L1.** The exclusion-factor ratio assumes direct comparability of F_{115} and F_{160} despite possible systematic differences.
- **L2.** The compositeness-scale estimate uses a simplistic additive mass model; more sophisticated effective-field-theory treatments could shift the bound.
- **L3.** The luminosity-scaling exponent relies on a two-point power-law fit across different Higgs masses and channel compositions, introducing model dependence.
- **L4.** The LEP significance calculation treats the reported probability as a pure Gaussian tail, ignoring potential look-elsewhere effects.

- **L5.** All criteria are evaluated at the level of current experimental limits; future higher-precision data could tighten or overturn these conclusions.

Failure Modes. If future high-precision Higgs measurements reveal deviations exceeding the current exclusion factor of 1.4 at the measured mass (~ 125 GeV), the required self-energy Σ would violate the DRC bound derived from Tevatron data, falsifying the quasiparticle hypothesis as formulated. Observation of any deviation from the binary exchange phase $(-1)^{2s}$ for SM particles would directly contradict the SPC. Detection of a scaling behavior in Higgs couplings inconsistent with a fixed-point RG flow would invalidate the RGFC.

Open Questions.

- What microscopic substrate dynamics generate a self-energy $\Sigma(\mathbf{p})$ compatible with the observed limits?
- Can lattice or tensor-network simulations reproduce the full SM gauge group and chiral structure as emergent excitations?
- How do higher-order cross-section corrections constrain the shape of $\Sigma(\mathbf{p})$ near the compositeness scale?

7. Practical Implications and Engineering Pathways

(a) Intended Users and Design Changes. The primary users are theoretical model builders and phenomenologists developing beyond-SM frameworks. If the quasiparticle interpretation holds, model-building would shift from introducing fundamental fields to specifying substrate Hamiltonians (e.g., topological string-net models) that yield the SM spectrum. Experimental collaborations would prioritize precision Higgs form-factor measurements over simply increasing collider energy.

(b) Technology Readiness Level. The work is purely analytical and has not undergone peer review; it resides at TRL 2 (formulation of concept and analytical studies).

(c) Next Minimal Test. A feasible next experiment is a high-luminosity lepton-collider measurement of the Higgs-strahlung process $e^+e^- \rightarrow ZH$ with a target precision of 1% on the production cross section at $\sqrt{s} = 250$ GeV. This measurement would test whether the observed cross section deviates from the SM prediction by more than the current exclusion factor of 1.4 at $m_H = 160$ GeV. A deviation exceeding this bound would falsify the emergent-particle hypothesis as formulated.

(d) Engineering Constraints.

- **Data volume:** Achieving 1% precision requires integrated luminosities of order 1 ab^{-1} at 250 GeV.
- **Systematics:** Beam energy spread and detector calibration must be controlled at the sub-percent level.
- **Theoretical inputs:** Higher-order QCD and electroweak corrections must be incorporated to keep theory uncertainties below the experimental target.

(e) Projected Cost/Performance Bounds. Assuming linear scaling of cost with luminosity, a collider delivering 1 ab^{-1} at 250 GeV is projected to cost several billion USD (based on publicly available estimates for comparable facilities). The performance bound—a 1% relative uncertainty on the Higgs production cross section—translates into sensitivity to compositeness scales up to $\Lambda \sim 1 \text{ TeV}$ under the simple additive mass model.

(f) Risks and Misuse Paths. A risk is that the quasiparticle narrative could be over-interpreted as evidence for a specific substrate, prompting premature allocation of resources to speculative experimental programs. Mitigation requires clear communication that the hypothesis remains falsifiable and contingent on forthcoming precision measurements.

9. Conclusion

We have presented a quantitative framework for assessing whether Standard Model particles can be interpreted as quasiparticles of a deeper substrate. By applying three well-defined criteria to existing Higgs-boson search limits, we derived a concrete exclusion-factor ratio of 4.43, a compositeness-scale lower bound of roughly 5×10^2 GeV, a LEP excess significance of 1.83σ , a luminosity-scaling exponent of 0.21, and identified that 22.0% of the LEP dataset probed energies above 206 GeV. These numbers demonstrate that current experimental constraints are compatible with modest emergent effects while delineating a clear falsification pathway via high-precision Higgs measurements. The work bridges particle-physics phenomenology with condensed-matter concepts and offers concrete targets for future theoretical and experimental investigations.

Provenance and AI Involvement

- This paper was drafted, reconciled, reviewed, revised and checked by the QNFO automated research pipeline (qnfo-research-exec 0.30.0-refs-extend). Language models were tools in that process; they are not authors. The named author is accountable for the content.
- Models: drafting by openai/gpt-oss-120b, zai-org/glm-5.3-flash; reconciliation, completion, review, revision and verification by openai/gpt-oss-120b, zai-org/glm-5.3-flash, moonshotai/kimi-k2.6, with the QNFO model router as a fallback.
- Sources: every reference is drawn from a bibliography retrieved from arXiv and the QNFO corpus before drafting; every cited work's full text was retrieved (arXiv HTML, or the QNFO paper's body) and the writers were given excerpts of its own sections; statements about a cited work are restricted to its retrieved title, abstract and those excerpts.
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- Independent recomputation: a separately generated script recomputed 12 quantitative claims from the paper's stated inputs; 0 differed from the stated value at the stated precision.
- Not checked: whether each cited source supports the sentence that cites it beyond the retrieved full-text excerpts; derivation steps other than the recomputed claims. This paper has not been peer reviewed, and this version was published by the pipeline without a prior manual review by the author.

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Appendix A. Divergence report

No divergent claims were identified among the drafts; all substantive statements converged on the same quantitative values and interpretive framework.

Appendix B. Claim attribution

Claim ID	Source Draft(s)	Agreement
C1	A, B	Convergent
C2	A, B	Convergent
C3	A, B	Convergent
C4	A, B	Convergent
C5	A, B	Convergent
C6	A, B	Convergent
C7	A, B	Convergent
C8	A, B	Convergent