

Hadron Physics in the Age of AI

From Calculation to Structural Intelligence

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1. The Irreversible Transition: Artificial Intelligence

- Coding is becoming trivial.
- Symbolic QFT manipulation is automated.
- Loop integrals, RG equations, spectral reconstruction — generated instantly.
- The barrier to calculation is collapsing.

Fact

We cannot stop this transition.

2. What Has Actually Changed?

Before AI:

- Years to master formalism
- Calculation as intellectual gatekeeping

After AI:

- Formal manipulation outsourced
- Access democratized

Physics is no longer computation-limited.

3. But Physics Was Never Calculation

Physics is about:

- Symmetry
- Scale
- Universality
- Effective description
- Conceptual unification

Core Thesis

AI performs operations. Physicists construct structures.

4. Personal Observation

20+ years of QFT and nuclear theory training.

With AI:

- Code generation \uparrow
- Analytical speed \uparrow
- Hypothesis testing speed \uparrow

AI amplifies prior structural depth.

5. The Educational Crisis

If AI can compute QFT amplitudes:

- Should students still learn derivations?
- Should they memorize formalism?
- What is indispensable?

Central Question

What must remain uniquely human?

6. The New Core Competence

Four irreducible human abilities:

- ① Scale intuition
- ② Symmetry literacy
- ③ Consistency reflex
- ④ Narrative synthesis

7. Methodology: Three-Layer Model

Layer 1: AI Computation

- Symbolic manipulation
- Diagram evaluation
- Numerical solvers

Layer 2: Structural Interpretation

- Identify degrees of freedom
- Analyze limits ($T \rightarrow 0, \mu \rightarrow \infty$)
- Track symmetry breaking

Layer 3: AI Audit

- Ward identity check
- Scaling test
- Unitarity test
- Causality test

8. Reverse Physics Training

Step 1: Let AI compute amplitude.

$$\mathcal{M} = \bar{u}(p')\Gamma^\mu u(p)D_{\mu\nu}(q)\Gamma^\nu$$

Step 2: Student explains:

- What symmetry constrains Γ^μ ?
- What ensures transversality?
- What is the scaling in q^2 ?

Goal:

Calculation \rightarrow Physical Meaning

9. Contradiction Detection Training

Examples:

- Broken gauge invariance
- Violated Goldstone theorem
- Spectral function not positive definite

Student must answer:

Why is this physically impossible?

10. Multi-Story Integration Example (QCD)

Separate stories:

- KvBLL calorons
- Dyons
- Polyakov loop
- Chiral symmetry breaking
- Spectral broadening

Exercise:

Unify them into one physical picture

Confinement and chiral restoration emerging from topological structure.

11. Case Study: Spectral Function Reconstruction

AI can invert Euclidean correlator:

$$G(\tau) = \int d\omega K(\tau, \omega) \rho(\omega)$$

But:

- Is $\rho(\omega) > 0$?
- Does it respect sum rules?
- Is UV behavior correct?

AI produces output. Physicist validates structure.

12. Case Study: Hadron Decay in Medium

AI calculates width:

$$\Gamma(T, \mu)$$

Human must ask:

- Does chiral symmetry constrain mass shift?
- Is threshold behavior correct?
- Is phase space scaling physical?

Structure $>$ number.

13. Philosophical Shift

Old paradigm:

Knowledge = Mastery of Technique

New paradigm:

Knowledge = Mastery of Structure

14. Physics as Structural Compression

A theory is valuable if it:

- Compresses many phenomena
- Preserves symmetry
- Predicts limits

AI expands computation.

Human compresses meaning.

15. The Risk

Without structural training:

- AI-generated nonsense accepted
- Loss of physical intuition
- Collapse of conceptual coherence

Danger

Calculation without understanding.

16. The Opportunity

With structural training:

- Faster hypothesis testing
- Broader model exploration
- Cross-field integration

AI becomes intellectual accelerator.

17. Future Physicist

Human:

- Concept architect
- Consistency judge
- Cross-domain integrator

AI:

- Infinite patience
- Fast symbolic engine
- Rapid prototype generator

18. Educational Reform Proposal

Curriculum shift:

- Reduce repetitive derivation
- Increase conceptual integration
- Mandatory AI audit exercises
- Cross-model synthesis projects

AI does not replace physics.

It removes the computational barrier.

Physics becomes purely structural.

In the AI era,

The physicist is no longer a calculator.

The physicist is a designer of consistency.