From First Principles to Collider Phenomenology

Starting point of a model:
Lagrange Density Function

This is the Lagrangian of the Standard Model of particle physics. It encodes the interactions of all known elementary fermions and bosons that participate in electromagnetic, weak and strong dynamics. The extremely compact notation is possible thanks to symmetries.

The framework:
Quantum Field Theory

Quantum Field Theory is the framework that allows rigorously computing observable predictions based on a Lagrange density function. It unites the fundamental principles of Quantum Mechanics and Special Relativity, and allows the description of many-particle dynamics. One of its basic axioms is Micro Causality:

Two space-like separated operators always commute:

\[ [\phi(x_1), \pi(x_2)] = \begin{cases} \frac{i}{\hbar} \delta^{(3)}(\vec{x}_1 - \vec{x}_2) & \text{for } t_1 = t_2 \\ 0 & \text{for } (x_1 - x_2)^2 < 0 \end{cases} \]

From the axioms follows: CPT invariance, Unitarity, Spin-Statistics Theorem, No superluminal communication.

Special feature:
Spontaneous Symmetry Breaking

The embedding of the Higgs Boson is realized through a special mechanism: While the Lagrangian is invariant under the symmetries of the Standard Model, the ground state is not! This explains the elementary particle masses and leads to testable properties of Higgs boson dynamics in LHC experiments.

A powerful tool for rigorous predictions:
Perturbation Theory

Basic building blocks:
QED Feynman rules

Scattering amplitudes:

In perturbation theory basic Feynman diagrams can be drawn to represent particle processes. Each diagram can be translated into a formula that contributes to the physical scattering amplitude. The leading order contribution only has often tree graphs (see left), whereas higher orders have virtual loop graphs (see below).

The ultimate test ground:
Particle Collider Experiments

Scattering event at the LHC in the CMS detector (above). Comparison of data vs. theory prediction for a Higgs boson decay from the ATLAS detector (right).