Higgs Boson Physics

MPAGS Module

Problems

Problem 1

The Lagrangian for three interacting real fields ϕ_1, ϕ_2, ϕ_3 is:

$$\mathcal{L} = \frac{1}{2}\left(\partial_\mu \phi_i\right)^2 - \frac{1}{2}\mu^2 \phi_i^2 - \frac{1}{4}\lambda\left(\phi_i^2\right)^2$$

with $\mu^2 < 0$ and $\lambda > 0$, and where a summation of ϕ_i^2 over i is implied. Show that it describes a massive field of mass $\sqrt{-2\mu^2}$ and two massless Goldstone bosons.

Problem 2

Given the following Lagrangian density for interacting real scalar fields (σ, π):

$$\mathcal{L} = -\frac{1}{2}\left(\partial_\mu \sigma \partial^\mu \sigma + \partial_\mu \pi \partial^\mu \pi\right) + \frac{1}{2}m^2\left(\sigma^2 + \pi^2\right) - \frac{1}{4}\lambda\left(\sigma^2 + \pi^2\right)^2 - g\sigma$$

with $(\lambda > 0, g > 0)$

a) Estimate the Hamiltonian density $\mathcal{H}$ and locate the ground state of the system

b) Study the Goldstone effect at the limit $g \to 0$

Problem 3

Assume a scalar boson ϕ observed in the decay channel $\phi \to \gamma\gamma$. ϕ is produced through the gluon fusion and the vector boson fusion processes, which have distinct experimental signatures. The aim is to measure the signal strength modifiers μ_{ggF} and μ_{VBF} for each process, where $\mu = \frac{\sigma \cdot \mathrm{BR}}{\sigma_{SM} \cdot \mathrm{BR}_{\mathrm{SM}}}$. To this end an analysis with two signal regions, SR_1 and SR_2, is prepared. Each signal region is optimized to select one of the two production modes. Given, for each signal region i, N_i^{obs} observed events, n_i^{ggF} and n_i^{VBF} expected signal events from the Standard Model from each production mechanism, and n_i^b expected background, and assuming the experimental outcome given in Table 1:

a) Provide the likelihood function of the experiment.

b) Measure simultaneously parameters (μ_{ggF}, μ_{VBF}).

c) Measure parameters μ_{ggF} and μ_{VBF}.

d) Estimate the expected uncertainty for these measurements, at the experiment design level, i.e. before looking at the data, assuming the Standard Model.

Table 1: Expected and observed events for the experimental configuration.

	SR_1	SR_2
N^{obs}	24	8
n^{ggF}	16.2	2.1
n^{VBF}	0.9	4.2
n^b	5.2	0.9

Problem 4

Assume the Orsay electron beam dump experiment described in Phys. Lett. B**229** (1989) 150.

a) Estimate the experimental acceptance for Higgs boson decays, as a function of its life-time (τ).
b) Express the acceptance as a function of the Higgs boson mass (m_H) for the Standard Model.
c) Estimate the expected number of events for a Standard Model Higgs boson, as a function of m_H.
d) Estimate the expected energy distribution in the Cerenkov calorimeter for various m_H values, with and without accounting for the energy resolution of the detector.
e) Estimate the expected number of events for the Standard Model Higgs boson as a function of m_H, including an energy requirement of 750 MeV in the calorimeter.

Problem 5

Assume the global electroweak fit as described in Eur. Phys. J. C**60** (2009) 543.

a) Using only the M_W mass measurement as input and assuming perfect knowledge of all input parameters except M_H, write the likelihood function and perform the maximum likelihood scan versus M_H, assuming 1%, 0.1% and 0.01% precision on the M_W measurement. [Use Equation (4.10)]
b) Repeat a) assuming 10%, 1% and 0.1% precision on m_t
c) Repeat a) and b) but this time for $\sin^2\theta^{\ell}_{\mathrm{eff}}$ assuming a relative precision 10^{-3}, 10^{-4} and 10^{-5}. [Use Equation (4.11)]
d) Repeat c) assuming 10%, 1% and 0.1% precision on m_t.
e) Repeat the above combining the M_W and $\sin^2\theta^{\ell}_{\mathrm{eff}}$ measurements.
f) What are your remarks?