08.128.742 Quantum Field Theory III
The Standard Model and Electroweak Theory

Homework set 4

Due January 14, 2021; e-mail (photo or scan) to yu001@uni-mainz by start of discussion session
Please note how long it took you to solve each problem

4-1, 20 pts. Design a collider analysis to measure the W boson mass in the scattering process $pp \to W^{\pm}X$, $W^{\pm} \to \ell^{\pm}\nu$, where $\ell = e$ or μ. What collider observable can you construct and how do you extract the W boson mass? Compare with the published ATLAS analysis (led by Prof. Matthias Schott of JGU Mainz), arXiv:1701.07240. Why does the collider observable in the $\ell^{\pm}\nu$ final state have better mass resolution than the simple dijet invariant mass for the $W \to jj$ final state?

4-2, 80 pts. Consider Higgs boson production at the LHC. We will focus on understanding complications about extracting Higgs couplings at pp colliders.

A, 10 pts. Draw and list the five most dominant production modes at $\sqrt{s} = 13$ TeV and their cross sections.

B, 20 pts. The κ-framework is a straightforward modification of Higgs couplings to test experimentally for non-SM scattering rates of the 125 GeV Higgs boson. In this framework, all tree-level couplings of the Higgs boson are multiplied by their own κ_i, while the two leading loop-induced couplings of hgg and $h\gamma\gamma$ are also multiplied by κ_g and κ_γ, respectively. The SM case requires all $\kappa_i = 1$, while an experimental result favoring $\kappa_i \neq 1$ would indicate the presence of new physics. Write the Feynman rules for hgg, $h\gamma\gamma$, hW^+W^-, hZZ, and hbb in the κ framework.

C, 20 pts. Determine the cross section dependence on κ_i for $gg \to h \to \gamma\gamma$ in the κ-framework. Given a measurement of this event rate, can you individually determine the two corresponding κ parameters? What happens when you include a measured cross section for $gg \to h \to ZZ^*$? Does the situation improve when you add more decay modes or more production modes?

D, 20 pts. Identify the (non-unique) set of necessary assumptions in order to extract individual κ couplings from LHC data. *Hint:* Consider the role of the Higgs width. In general, the Higgs could decay to non-SM final states, which would be an additional contribution to the total Higgs width, $\Gamma_{\rm BSM}$.

E, 10 pts. Match the κ_b coupling modifier to the coefficient of a dimension-6 operator (from HW 2-2). In general, the κ-framework is a restricted subset of dimension-6 effective operators that affect Higgs physics.

F, Bonus, 20 pts. At an e^+e^- collider, the additional kinematic certainty from the initial state allows an *inclusive* measurement of Higgs production in the $e^+e^- \to Zh$ channel. What observable gives this inclusive rate? How does having an inclusive rate for Higgs production now allow the κ-framework system of equations to close? *Hint:* Consider the system of equations from the inclusive rate measurement and the $e^+e^- \to Zh$, $h \to ZZ^*$ decay. This technique is known as the "recoil-mass" measurement and is a primary motivation for an e^+e^- Higgs factory.