08.128.742 The Standard Model and Electroweak Theory Quantum Field Theory III

Felix Yu

Homework set 4

Due June 20, 2024 by start of discussion session
Please note how long it took you to solve each problem

4-1, 0 pts. Reading assignments: For a good overview of the fundamentals of detector physics, read through the Particle Data Group review entitled "Passage of particles through matter," as well as the more specialized (but still general) overviews "Particle detectors at accelerators" and "Particle detectors for non-accelerator physics." In addition, read the review "Kinematics," which is relevant for this homework set. The PDG reviews can be found at "https://pdg.lbl.gov/2022/reviews/contents_sports.html" and are also available on Moodle.

4-2, 30 pts. The W mass measurement. Based on the PDG "Kinematics" review, and reading over the published ATLAS analysis (led by Prof. Matthias Schott of JGU Mainz), arXiv:1701:07240:

A, 10 pts. Draw the leading order diagram for $pp \to W^+ \to \ell^+\nu$ production from the LHC (in a 4-flavor PDF scheme) and write the matrix element. Here, ℓ is either the electron or muon.

B, 5 pts. Given that the neutrino escapes the event without being detected, how many components of the neutrino 4-momenta can still be measured or constrained?

C, 15 pts. Construct the transverse mass variable based on part (B) and identify the kinematic configuration of the lepton+neutrino system where the transverse mass variable is equal to the W mass. How does the variable change if there are additional jets in the system?

Extra credit, 5 pts. 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?

4-3, 70 pts. Design a collider analysis for the following SM processes at LHC by ATLAS or CMS. This means: (i) identify the collider signature of the process or new physics particle, (ii) identify the main reducible and irreducible SM backgrounds, (iii) what kinematic cuts will help eliminate the reducible backgrounds, and (iv) what further kinematic cuts will enhance the signal compared to the remaining backgrounds.

A, 35 pts. The Standard Model production of same-sign W bosons, $pp \to W^\pm W^\pm jj$.

B, 35 pts. The Standard Model double Higgs production $pp \to hh$, which is relevant for extracting the trilinear Higgs coupling. (*Hint:* you can choose the collider signature where one Higgs boson decays to $\gamma\gamma$ and the other decays to $b\bar{b}$.)