PHYS 6213: Advanced Particle Physics
Problem Set 4 – due April 08

PROBLEM 1: Top Quark Pair Production from Gluon Fusion

At the CERN Large Hadron Collider (LHC), gluon fusion is the dominant source for top quark pair production.

(a) Write down the relevant QCD Lagrangian density for $gg \to t\bar{t}$ including $\mathcal{L}_{\text{DFP}}$, then draw Feynman diagrams and describe Feynman rules for propagators and vertices.

(b) Draw Feynman diagrams for $g(p_1)g(p_2) \to t(p_3)\bar{t}(p_4)$ then find the matrix element squared

$$\langle \sum_{\lambda,s} |M|^2 \rangle (gg \to t\bar{t})$$

in terms of Mandelstam variables

$$ s = (p_1 + p_2)^2, \quad t = (p_2 - p_3)^2, \quad u = (p_1 - p_3)^2, $$

summing over spins, polarizations, and colors as well as averaging over polarizations and colors for the initial state gluons.

PROBLEM 2: Top Quark Pair Production in pp Collisions

Apply MadGraph with parton distribution functions and evaluate the cross sections:

(a) $\sigma(pp \to t\bar{t} + X)$,

(b) $\sigma(pp \to t\bar{t} \to bu\bar{d}\,\bar{b}\mu^-\bar{\nu}_\mu + X)$, and

(c) $\sigma(pp \to t\bar{t}H + X)$,

at the LHC and future hadron colliders, for collider energy $\sqrt{S} = 13$ TeV, 14 TeV, and 100 TeV. Let us choose the renormalization scale (μ_R) and the factorization scale (μ_F) to be invariant mass of the top quark pair $\sqrt{s} = M_{t\bar{t}}$, then apply a K-factor of 2 for the total cross section.