Collider Physics, Fall 2009

Homework Assignment # 5

(“Due” Tuesday, October 20.)

Problems:

1. W Production at Hadron Colliders
   - Using the estimate of the $Z + X$ cross sections in Lecture 11 as a template, estimate the leading-order cross section for $W + X$ production at the Tevatron ($p\bar{p}$ at $\sqrt{s} = 2.0 \text{ TeV}$) and at the LHC ($pp$ at $\sqrt{s} = 14 \text{ TeV}$).
   - Generate event samples for $W$ production at the Tevatron and the LHC using MadGraph. Compare the MG cross sections to the simple estimate above. Explore the dependence of the result on the choice of renormalization and factorization scales (vary them between $M_W/2$ and $2M_W$), and on the choice of the p.d.f. set (for example, compare CTEQ6L1 with MRST2002NLO - both are available on the web interface). Comparing with the NLO answers: $\sigma_{\text{NLO}}(W + X) = 25 \text{ nb}$ at the Tevatron, $183 \text{ nb}$ at the LHC, derive the “K-factors” for this process.

2. Transverse Mass
   - Show that the transverse mass variable $M_T$ defined in Lecture 12 obeys $0 \leq M_T \leq M_W$, if $p_T(W) = 0$. Show that the same formula holds for $p_T(W) \neq 0$ to linear order in $p_T(W)/M_W \ll 1$. Show that (in the $p_T(W) = 0$ limit) there is a Jacobian peak in the event distribution in $M_T$.
   - Simulate a sample of $p\bar{p} \rightarrow W^+ \rightarrow \mu^+ \nu_\mu$ at the Tevatron using Madgraph. Plot the distributions in $p_T$ of the muon and in $M_T$.

3. Z+Jet with Madgraph
   - Simulate a sample of $Z + 1$ jet events at the Tevatron (at parton level) using Madgraph. Impose cuts on the jet used by analyses discussed in Lecture 13: $p_T(j) > 20 \text{ GeV}$, $|\eta(j)| < 2.5$. (The rapidity cut models the detector’s geometry: it must have a hole to let the beams in! The $p_T$ cut is to avoid soft and collinear singularities, and regions where fixed-order perturbation theory fails.) Plot the distribution of events in the $p_T$ of the $Z$. Compare with Fig. 1 on the next page. Comment on any discrepancies.
Figure 1: Distribution of events in $Z$ transverse momentum, measured by the DØ collaboration at the Tevatron Run II (PRL 100, 102002, 2008).