835 Homework set VII (due Dec. 14, the last day of class)

You need to work out one of the three problems to get full credits. You should choose the suitably challenging ones for your own sake. You are of course encouraged to work out as much as you can.

Level I Problems:
(1) Exercise on page 237, *Collider Physics*: W decay distributions.

(2) Exercise on page 437, *Collider Physics*: $H \to W^+W^-$.

(3) In searching for a new gauge boson $W'^{\pm}$ beyond the SM, consider that the W' decays to these (experimentally clean) channels

$$W'^{\pm} \to e\nu_e;\ \mu\nu_\mu;\ tb;\ \text{and } W^{\pm}Z. \tag{1}$$

State how to discover this particle (kinematically) with what final states, and list the SM processes that are the backgrounds for each of the above channels.
(Note: You must specify the experimentally identifiable final state particles when considering the signal and backgrounds. These backgrounds that are identical to the signal final states are called "irreducible" backgrounds, and those that would look the same at the detector level are called "reducible" or "faked" backgrounds.)

Level II Problems:

(1) Same as (3) in Level I.
(2) Tabulate or plot the following total cross sections numerically in pp collisions versus the c.m. energy 2 TeV< $\sqrt{S}$ <40 TeV,

$$\begin{aligned}
&pp \to \gamma^*,\ Z^* \to \mu^+\mu^-,\ t\bar{t},\\
&pp \to W^+W^-,\ ZZ,\\
&pp \to Z^* \to Zh.\\
&pp \to W^*W^* \to h,
\end{aligned}$$

where h is the SM Higgs mass and assume $m_h = 120$ GeV.
(Note: For the calculations, you may use whatever techniques and packages available to you. You do not need to present too fine intervals in $\sqrt{s}$. You

should remember some cross section values at the LHC energy $\sqrt{S} = 14$ TeV.)

(3) The `Goldstone-boson Equivalence Theorem` (ET): At high energies $E \gg M_{W,Z}$ (more accurately, $s, |t|, |u| \gg M^2_{W,Z}$), the scattering amplitude involving external longitudinal gauge bosons (W_L, Z_L) is equivalent to that replacing them by the corresponding eaten Goldstone bosons (w, z),

$$\begin{aligned} i\mathcal{M}(W_L, Z_L,\ ...) &= i\mathcal{M}(iw, iz,\ ...) + \mathcal{O}(M_W/E), \\ \text{or}\ \ i\mathcal{M}(\epsilon^W_L, \epsilon^Z_L,\ ...) &\approx i\mathcal{M}(ip^W/M_W, ip^Z/M_Z,\ ...). \end{aligned}$$

For the explicit step, $\epsilon^\mu(p)_L \to ip^\mu/M$, I call it to "scalarize the vector-boson amplitude".
Derive the squared matrix elements for (a) $H \to W^+W^-$ and (b) $W^+b \to t$ with both the full and ET calculations. Compare the procedure and results.

Level III Problems:
(1) Same as (2) in Level II.

(2) Same as (3) in Level II.

(3) Consider to search for a charged Higgs boson $H^\pm$ at the LHC in a two-Higgs doublet model (either a generic one as in p. 452 or in the minimal SUSY model).
List a few leading decay channels as feasible signatures for the signal searches. Propose the leading production channels (you do not have to calculate them, but just list them with your supporting arguments.) Comments on the SM backgrounds to the signals you proposed.
Note: Consider a mass $M_W < m_{H^\pm}$ to a few hundred GeV. Concentrate on the couplings to the SM particles.