Dear Colleagues, March 30, 2020

this is a short report on the calculation of the polarized Bethe-Heitler (BH) process (lepton-pair production, see Fig. 1) in scattering of real photons on protons, based on the papers [1] (unpolarized case) and [2] (polarized case).

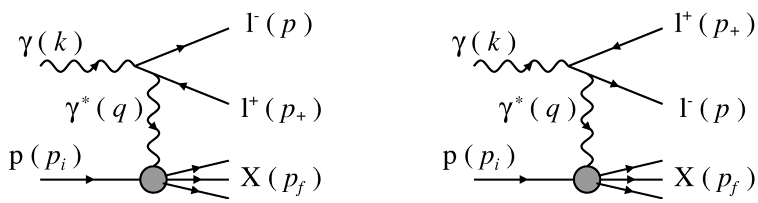

Figure 1: Feynman graphs for Bethe-Heitler lepton pair production.

The algebra is somewhat involved but I have managed to code the expressions for the unpolarized BH cross-section in the case when only one lepton (say, electron) is detected — this is given by Eq. (2.7) of [1] — as well as the polarized cross-section under the same conditions — given by Eq. (7) of [2]. I encountered several problems:

1) what type of structure functions to use in these cross-sections, meaning W_1 and W_2 in [1] and G_1 and G_2 in [2]; this is related to the magnitude of q^2 of the virtual photon involved in the process, which varies a lot depending on the kinematics, hence different physics regimes become pertinent: if $|q^2|$ is small, one needs atomic (!) form factors, while if it is comparable to inverse proton radius squared, one needs nucleon elastic form-factors, and if it is even larger yet, one needs the DIS-scale $g_1(x, Q^2)$ and $g_2(x, Q^2)$ instead. Ultimately I used the usual nucleon elastic form-factors to obtain at least good estimates, i. e. parameterization (B44) of [1] without the delta-func and formulas (9) of [2]. I have no gut-feeling yet of the error I am committing by adopting these assumptions.

2) Which angular range for θ_e, the electron scattering angle, to cover. This is related to the question of integration stability as the double integrals fall off rapidly with θ_e and my Mathematica is struggling with them — and I would need more time to see what causes the poor convergence of adaptive integration in those domains. I also took a different approach in polarized vs. unpolarized cases: in the former case I used direct 2d integration, in the latter case I used 1d integration within a 1d integration, which is slower and even less stable.

Figure 2 summarizes the results for low angles ($0^\circ \le \theta_\mathrm{e} \le 30^\circ$); the wiggles betray numerical integration woes. If the calculations are sort-of correct, one can see that the cross-sections are very much forward peaked and comparable to our 150 μb "beacon", yet note that the $\mathrm{d}\sigma_\mathrm{BH}$ shown are still differential in p_e and Ω_e. The asymmetry increases with θ_e but I guess this would not hurt since both unpolarized and polarized cross-sections fall dramatically with θ_e. Note that one should also consider the $\mu^+\mu^-$ process; according to [1], for large transverse momenta of the produced particles, the cross-section is nearly independent of the mass of the particle produced.

References

[1] Y.-S. Tsai, Rev. Mod. Phys. **46**, 815 (1974); erratum Rev. Mod. Phys. **49**, 421 (1977).

[2] T. Gehrmann, M. Stratmann, Phys. Rev. D **56**, 5839 (1997).

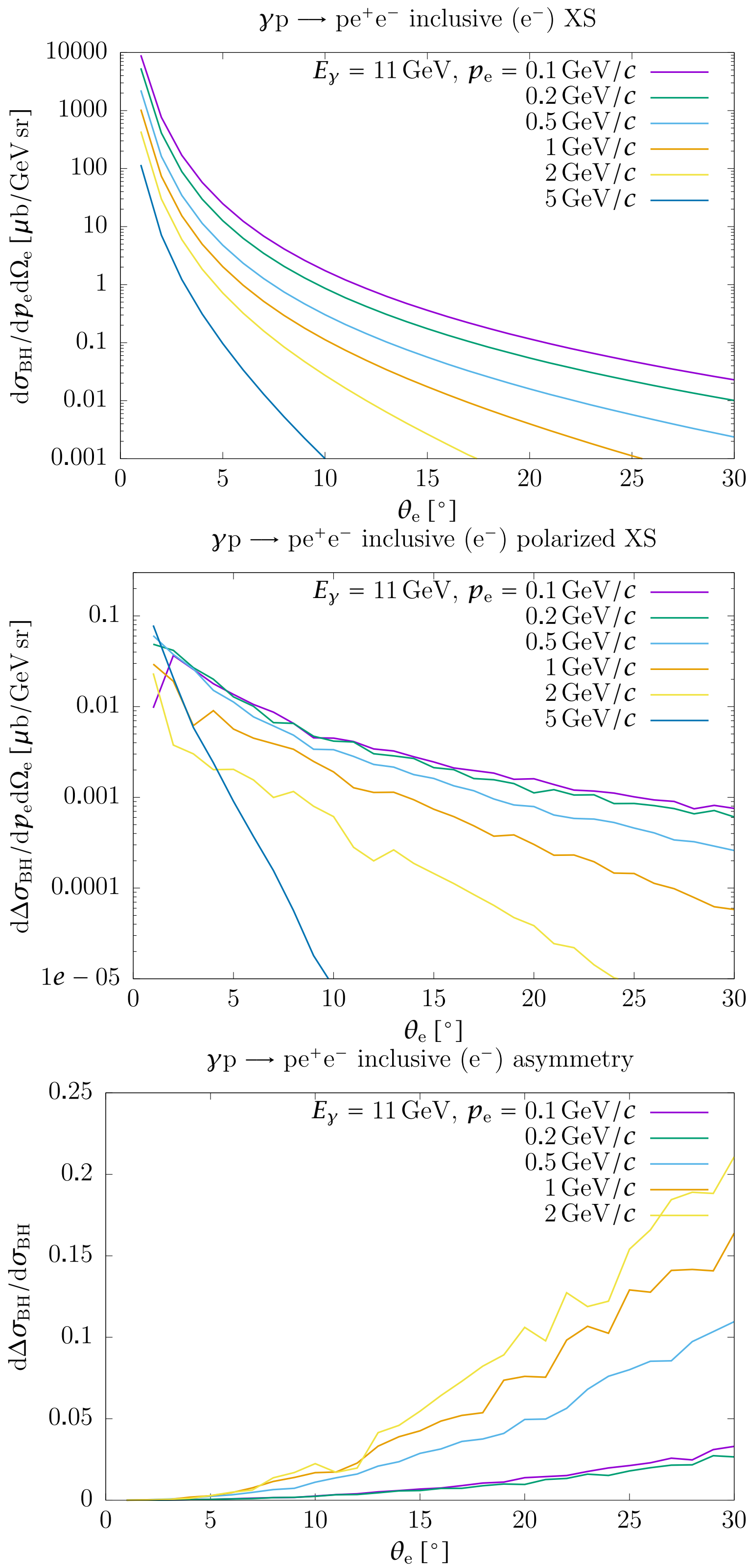

Figure 2: Bethe-Heitler unpolarized cross-section (top), polarized (center), asymmetry (bottom) for $E_\gamma = 11\,\mathrm{GeV}$ and different p_e, as function of θ_e.