A new Generator for Wide Angle Bremsstrahlung

Ch. Berger[a,b] and P. Kandel[a,c]

[a] I. Physikalisches Institut der RWTH-Aachen, 52056 Aachen, Germany
[b]e-mail:berger@rwth-aachen.de
[c] Now at Ericsson, Herzogenrath, Germany

Abstract: A new generator for the simulation of elastic and inelastic wide angle bremsstrahlung is described. The generator is adapted to simulate events in the full kinematic plane accessible to the HERA collider experiments. A complete simulation of the final state is included. Standard Monte Carlo routines are used to ensure an efficient production of events with equal weights.

1 Introduction

The process

$$e + p \rightarrow e + p + \gamma \tag{1}$$

is one of the simplest reactions which can be studied at the HERA ep collider. Demanding the scattered electron and the photon to be measured in the HERA detectors, i.e. in a polar angle range[1] $1^\circ < \Theta < 179^\circ$ the phase space is restricted to the so called "wide angle bremsstrahlung" regime. This kinematic domain is characterized by the fact that the invariant mass squared $\hat{s}$ of the $e\gamma$-system and $\hat{t}$, the four momentum transfer squared between the in and outgoing electron are very large compared to m^2, the electron mass squared.

Neglecting photon radiation at the hadronic side the cross section can be calculated from the Feynman-diagrams in fig. (1). In this figure also the inelastic bremsstrahlung

$$e + p \rightarrow e + \gamma + X \tag{2}$$

is included, where X denotes an arbitrary hadronic final state. With $X = p$ the limiting case of elastic wide angle bremsstrahlung is retained.

2 Elastic wide angle bremsstrahlung

The cross section formula for reaction (1) cannot simply be taken from QED textbooks like [1] because the proton structure has to be taken into account. Formulas for the fully differential cross section can be found in refs. [2, 3]. Here we follow the approach of Courau and Kessler [4]

[1]The HERA coordinate system puts the z-axis along the direction of the incoming proton.

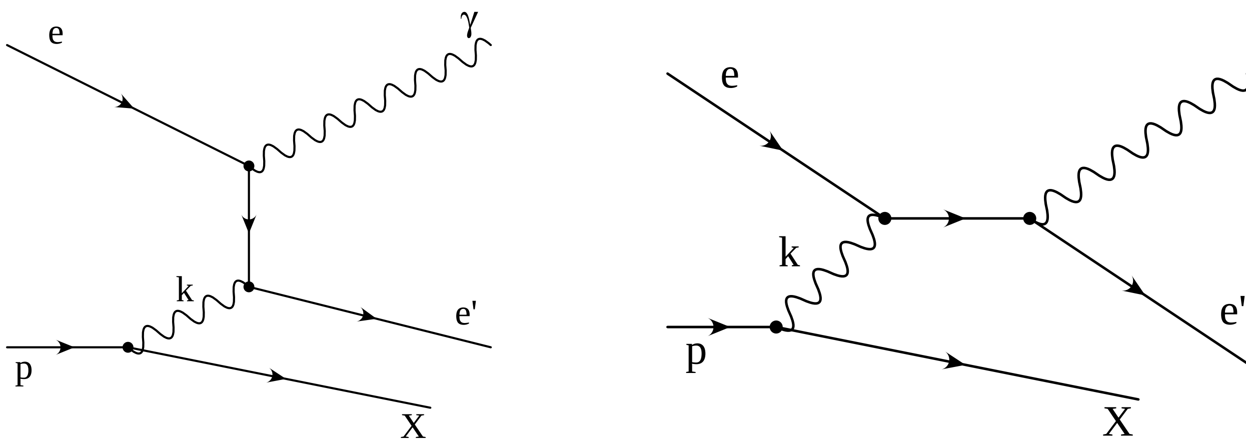

Figure 1: *Feynman-diagrams for bremsstrahlung off the electron lines.*

where the differential cross section is given as a product of photon flux factors and differential cross sections for the virtual Compton effect $\gamma^* + e \to \gamma + e$. The cross section is written as sum of a magnetic and electric term

$$\frac{d\sigma}{dk^2 dydzd\phi} = \frac{d\sigma^M}{dk^2 dydzd\phi} + \frac{d\sigma^E}{dk^2 dydzd\phi} \quad , \tag{3}$$

where $k^2 = (p - p')^2$ is the mass squared of the virtual photon radiated from the proton. Furthermore

$$y = \frac{e \cdot e'}{e \cdot k} = \frac{1}{2}(1 - \cos\theta_{cms}) \tag{4}$$

is connected to the scattering angle $\theta_{\rm cms}$ in $e\gamma^*$ subsystem and

$$z = \frac{e \cdot k}{e \cdot p} = \frac{\hat{s} + |k^2|}{S - m_p^2} \tag{5}$$

(where S is the ep center of mass energy squared) can be interpreted as the fractional momentum of the virtual photon in the proton infinite momentum frame. Finally ϕ is the angle between the $e\gamma$-plane and the proton scattering plane. With these definitions the magnetic and electric cross sections read

$$\frac{d\sigma^M}{dk^2 dydzd\phi} = \Gamma_M \cdot \left(\frac{d\sigma_t}{dyd\phi} + \epsilon \frac{d\sigma_l}{dyd\phi} + \epsilon \frac{d\sigma_p}{dyd\phi} + \sqrt{2\epsilon(\epsilon+1)} \frac{d\sigma_i}{dyd\phi} \right) \tag{6}$$

and

$$\frac{d\sigma^E}{dk^2 dydzd\phi} = \Gamma_E \cdot \left(\frac{d\sigma_t}{dyd\phi} + \frac{1+\epsilon}{2\epsilon} \frac{d\sigma_l}{dyd\phi} + \frac{d\sigma_p}{dyd\phi} + \sqrt{\frac{2(\epsilon+1)}{\epsilon}} \frac{d\sigma_i}{dyd\phi} \right) \quad . \tag{7}$$

Herein Γ_M and Γ_E are given by

$$\Gamma_M = \frac{\alpha G_M^2}{|k^2| \pi z} g_T \quad , \quad \Gamma_E = \frac{\alpha G_E^2 4 m_p^2}{|k^2|^2 \pi z} g_L \tag{8}$$

with

$$g_L = \frac{(1-z)|k^2| - z^2 m_p^2}{|k^2| + 4m_p^2} \tag{9}$$

$$g_T = \frac{(1-z)|k^2| - z^2 m_p^2}{|k^2| + 4m_p^2} + \frac{z^2}{2} \ . \tag{10}$$

The magnetic and electric formfactors $G_M(k^2)$ and $G_E(k^2)$ are only known empirically and are mostly approximated by the so called dipole formula [6]. The polarization parameter ϵ is defined by

$$\epsilon = \frac{g_L}{g_T} \ . \tag{11}$$

The virtual Compton cross sections formulas have been taken from the Mendez paper [7]. The longitudinal (index l), polarized (p) and interference term (i) vanish with k^2. Neglecting these terms reduces (3) to the equivalent photon approximation

$$\frac{d\sigma}{dk^2 dy dz d\phi} = (\Gamma_M + \Gamma_E)\frac{d\sigma_t}{dy d\phi} \ . \tag{12}$$

The sum $(\Gamma_M + \Gamma_E)$of the two flux factors equals the well known photon flux from a pointlike particle [5] if $G_M = G_E = 1$ is chosen. The Weizsäcker Williams approximation (WWA) neglects the k^2 dependence of the Compton cross sections and integrates over k^2 in the flux factors (8). Thus the incoming proton is replaced by a photon beam with a known energy spectrum. For a pointlike particle this spectrum has been calculated for the first time by Kessler [5], see also the interesting review by Budnev et al. [8]. A handy formula for the photon spectrum radiated by the proton can be found in ref. [9]. This calculation uses the dipole formula for the form factors.

It is important to note that, compared to the flux factor of a pointlike particle, the extremely steep decrease of (8) with k^2 results in a very good description of the cross section by the WWA in almost the entire phase space. This has been checked numerically by comparing the results of the new generator with a routine utilizing the WWA.

3 Inelastic wide angle bremsstrahlung

For higher values of $|k^2|$ inelastic processes, where the proton breaks up into a final state X, become more and more likely. We have simulated these reactions in the quark model by replacing the incoming proton by a beam of quarks with momentum fraction ξ of the incoming proton. The virtual photon flux from the quarks was calculated using the pointlike formula with a quark mass of 300 MeV. The virtual photon four vector k^μ and ξ uniquely determine the invariant mass W of the final hadronic system. For $|k^2| > 5$ GeV^2 and $\xi < 0.99$ (i.e. excluding the elastic peak) standard parton density parameterizations can be used. The final state was then simulated with the help of the JETSET7.4 routine [10].

In order to also include resonance production, $ep \to e\gamma R$, quasielastic processes with $|k^2| < 5$ GeV^2 and $m_p < W < 1.8$ GeV were simulated in addition. This was achieved by replacing the sum of the parton densities in the usual way by the proton structure function F_2 which was taken from the empirical fits of ref. [11]. The contribution of the continuum with $W > 1.8$ GeV is neglected in this approach. For the simulation of the final state in the resonance region a many body phase space model was applied.

The approach described here follows the method used in the earlier EPCQU generator [12]. The generator COM200 [13] uses a different ansatz, where the photon flux is calculated directly from F_2 and the known quasielastic cross sections in the resonance region [4]. It is therefore not surprising to see differences in the inelastic cross section up to 40%. The detailed reasons are not yet understood and require additional investigations. In the kinematic domain of the "Very low Q^2 spectrometers" of the HERA experiments these differences are unimportant because the inelastic contribution is very small.

Open questions remain, which need further study. It is e.g. unclear if real photon radiation from the quark lines in the quark model calculations can be neglected. Furthermore it should be noted that the new package does not yet include radiative corrections. The inclusion of these contributions at least in the collinear approximation (like done in EPCQU) is very desirable. This method is described in ref. [14]. A more detailed discussion of radiative corrections to wide angle bremsstrahlung can be found in ref. [15].

4 The WABGEN package

The elastic and inelastic cross section is numerically calculated using the Monte Carlo package BASES [16]. The package SPRING, which is included in the same distribution then generates weight 1 events in the selected region of phase space. The program calculates from the generated z and k^2 the four momentum of the virtual photon. After generating the kinematic variables in the photon electron CMS, the four momenta of all particles are computed in the HERA laboratory system and stored in H1 banks. In order to check the transformations the four-momentum conservation is controlled numerically for each event. The program code, a users manual and further documentation can be found in the directory /h1/h1gen/wabgen at the DESY workstation cluster. Because the program was developed within the H1 collaboration it contains H1 specific features like the BOS bank system, the H1 random number generator etc. For other computer systems some adaption work is necessary. In order to support this work the sources of all routines can be downloaded from http://mozart.physik.rwth-aachen.de/publications.html.

References

[1] R. Gastmans and T.T. Wu, The ubiquitious photon, Clarendon Press, 1990

[2] L.W. Mo and Y.S. Tsai, *Rev. Mod. Phys.* **41**, 205 (1969)

[3] A. Akhundov et al., *Z. Phys.* C **45**, 645 (1990)

[4] A. Courau and P. Kessler, *Phys. Rev.* D **46**, 117 (1992)

[5] P. Kessler, *Nuovo Cimento* **17**, 809 (1960)

[6] R. Hofstadter, *Rev. Mod. Phys.* **28**, 214 (1956)

[7] A. Mendez, *Nucl. Phys.* B **145**, 199 (1978)

[8] V.M. Budnev et al., *Phys. Reports* **15**, 1 (1974)

[9] B.A. Kniehl, *Phys. Lett.* B **254**, 267 (1991)

[10] T. Sjostrand, CERN-TH 7112/93, 1993

[11] F.W. Brasse et al., *Nucl. Phys.* B **29**, 421 (1972)

[12] F. Raupach, Proceedings 'Physics at HERA', Eds. W. Buchmüller, G. Ingelman Vol 3., 1473,1991

[13] T. Carli et al., Proceedings 'Physics at HERA', Eds. W. Buchmüller, G. Ingelman Vol 3., 1468,1991

[14] T. Köhler, Proceedings 'Physics at HERA', Eds. W. Buchmüller, G. Ingelman Vol 3., 1526,1991

[15] H. Anlauf et al.,*Z. Phys.* C **52**, 655 (1991)

[16] S. Kawabata, *Comp.Phys.Commun.* **41**, 127 (1986)