Radiative corrections to the beam spin asymmetry in photon electroproduction ($\vec{e}p \to ep\gamma$)

H. Fonvieille

Radiative Corrections to the Beam Spin Asymmetry in Photon Electroproduction $\vec{e}p \to ep\gamma$

H.Fonvieille
LPC-Clermont, November 2006

We have measured at MAMI the beam single spin asymmetry (SSA) in exclusive photon electroproduction $\vec{e}p \to ep\gamma$:

$$SSA \;=\; \frac{d^5\sigma(h_e = +1/2) \;-\; d^5\sigma(h_e = -1/2)}{d^5\sigma(h_e = +1/2) \;+\; d^5\sigma(h_e = +1/2)}$$

with a longitudinally polarized beam, in the region of the $\Delta(1232)$ resonance. In this document the value of the radiative correction to this asymmetry is obtained for our kinematics. Although the correction is expected to be very small and negligible, its value is needed as a confirmation and for the purpose of systematic error estimate.

The kinematics are the following:

four-momentum transfer of the virtual photon	$Q^2 = 0.35$ GeV^2
total energy in the (γp) center of mass	W=1.190 GeV
polarization of the virtual photon	ϵ=0.48
azimuthal angle (lepton-hadron planes)	ϕ= 220 °
polar angle of Compton scattering in center of mass	$\theta_{\gamma\gamma CM}$ in [0 ° , 40 °]
incoming electron beam energy	$E_e = 0.88$ GeV
scattered electron energy	$E'_e = 0.40$ GeV
polar angle of scattered electron	$\theta_e = 59.9°$

Radiative effects to this process are described in detail in ref. [1]. The radiative correction is calculated by the **radcorr** code [2] written by M.Vanderhaeghen, in a version adapted to beam spin asymmetries.

1 Calculation scheme

One has to choose a model for the cross section of the process $ep \to ep\gamma$. This can be : Bethe-Heitler, or VCS Born, or the coherent sum of the two. Ideally one would need also a VCS non-Born part to have the most realistic cross section, but this is not implemented. So we choose the option "Bethe-Heitler + Born".

The code computes the cross sections for the two beam helicity states, $d^5\sigma(h_e = +1/2)$ and $d^5\sigma(h_e = -1/2)$ and then the desired SSA. The calculation is run in two different conditions, for the same input kinematics:

1. without radiative corrections. One gets the value of the asymmetry SSA_{NoRC} corresponding to the bare (Bethe-Heitler + Born) process.
2. with first order radiative corrections. The calculation is performed along the lines of ref. [1], and one gets the value of the asymmetry SSA_{RC} of the (Bethe-Heitler + Born) process convoluted by the radiative effects.

It is easy to show that for small asymmetries ($|SSA| \ll 1$) the radiative correction is **additive** to first order, i.e. the correction ΔSSA is such that: $SSA_{RC} = SSA_{NoRC} + \Delta SSA$. So the value of the correction ΔSSA will be obtained by taking the difference of the results of executions 1) and 2).

Specificity:
In the case of a single cross section, two types of corrections are calculated: 1) the **virtual** radiative correction δ_V due to graphs involving one supplementary virtual photon; 2) the **real internal** radiative correction δ_R (or internal bremsstrahlung) due to graphs involving one supplementary real photon at the interaction vertex.
In the case of an asymmetry, i.e. a ratio of cross sections, only the virtual correction δ_V is calculated. The internal bremsstrahlung is considered to be spin-independent, because it is limited to its soft photon part. Then the contribution of δ_R cancels in the numerator and denominator of the SSA.

2 Results

Below are the results when running the **radcorr** code in our kinematics.

column # 1	angle $\theta_{\gamma^*\gamma cm}$
column # 2	incoming beam energy
column # 3	scattered electron energy
column # 4	electron scattering angle
column # 5	angle between lepton and hadron planes
column # 6	photon electroproduction cross section for beam helicity +1/2
column # 7	photon electroproduction cross section for beam helicity -1/2 (five-fold differential: $d^5\sigma/(dk'_{lab}d\Omega'_{elab}d\Omega_\gamma^{cm})$)
column # 8	beam single spin asymmetry.

```
***************  result for cross section=(Bethe-Heitler +Born),
                 without Radiative Corrections
```

thcm deg	klab GeV	k'lab GeV	thel deg	phi deg	sigma+ (pb/GeV/sr/sr)	sigma- (pb/GeV/sr/sr)	SSA
5.0	0.88	0.40	59.9	220	3.468025e+00	3.468025e+00	0.000000e+00
10.0	0.88	0.40	59.9	220	2.831173e+00	2.831173e+00	-3.921424e-16
15.0	0.88	0.40	59.9	220	2.342656e+00	2.342656e+00	3.791331e-16
20.0	0.88	0.40	59.9	220	1.967668e+00	1.967668e+00	0.000000e+00
25.0	0.88	0.40	59.9	220	1.677233e+00	1.677233e+00	6.619373e-17
30.0	0.88	0.40	59.9	220	1.449290e+00	1.449290e+00	7.660462e-17
35.0	0.88	0.40	59.9	220	1.267994e+00	1.267994e+00	1.751148e-16
40.0	0.88	0.40	59.9	220	1.122265e+00	1.122265e+00	0.000000e+00

```
***************  result for cross section=(Bethe-Heitler +Born),
                 with First Order Radiative Corrections
```

thcm deg	klab GeV	k'lab GeV	thel deg	phi deg	sigma+ (pb/GeV/sr/sr)	sigma- (pb/GeV/sr/sr)	SSA
5.0	0.88	0.40	59.9	220	2.883393e+00	2.879390e+00	6.946411e-04
10.0	0.88	0.40	59.9	220	2.355367e+00	2.349164e+00	1.318641e-03
15.0	0.88	0.40	59.9	220	1.951526e+00	1.943300e+00	2.112180e-03
20.0	0.88	0.40	59.9	220	1.640584e+00	1.632463e+00	2.481216e-03
25.0	0.88	0.40	59.9	220	1.399453e+00	1.392033e+00	2.658231e-03
30.0	0.88	0.40	59.9	220	1.210035e+00	1.203571e+00	2.678356e-03
35.0	0.88	0.40	59.9	220	1.059282e+00	1.053814e+00	2.587568e-03
40.0	0.88	0.40	59.9	220	9.380475e-01	9.335021e-01	2.428687e-03

• The first table gives a zero asymmetry. This is normal since we have only the BH+Born cross section, which has no imaginary part.

Reminder: the beam SSA is proportional to the imaginary part of the VCS amplitude, which comes only from the VCS non-Born part.

• The second table indicates an SSA in the range of **7.0e-3 to 2.7e-3**. This is our best estimate of the radiative correction ΔSSA to the asymmetry in each θ-bin.

• The spin dependence of the virtual correction δ_V is small, because it comes only from numerical terms associated to the Bethe-Heitler graphs (cf. ref. [3, 4]). This explains why the total radiative correction to the beam SSA is so small.

3 Conclusions

In practice, the conclusions are twofold:

- the asymmetry that we have measured in the VCS channel does not need to be corrected for radiative effects, given the large statistical error bar attached to the experimental values (an asymmetry of 1-10 % with a statistical error bar of 3-4 %).

- a systematic error ΔSSA_{syst} on the asymmetry will be considered, related to uncertainties in the calculation of the radiative correction (at least two of them have been mentioned here: the cross section model and the soft photon limit).To estimate this error we consider a 100 % variation of the radiative correction. For the radiative correction itself we take the maximal value found in the table above. Therefore we will take:

$$\Delta SSA_{syst} = \pm 2.7 \cdot 10^{-3}$$

in each θ_{cm}-bin, to be added quadratically to the other systematic errors on the SSA.

Many thanks to Marc Vanderhaeghen and Barbara Pasquini for their help in the matter.

References

[1] M.Vanderhaeghen et al., Phys.Rev.C 62(1000) 025501.

[2] M.Vanderhaeghen, private communication.

[3] David Lhuillier, PhD Thesis CEA-Univ.Caen, DAPNIA/SPhN-97-01T, France (1997).

[4] ref.[1] section III-C.