Contribution of hard photon emission to charge asymmetry in elastic lepton-proton scattering

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Radiative Corrections to the exclusive process

$$A_1(p_1) + A_2(p_2) \rightarrow \sum_{i=1}^{n} B_i(p_i')$$

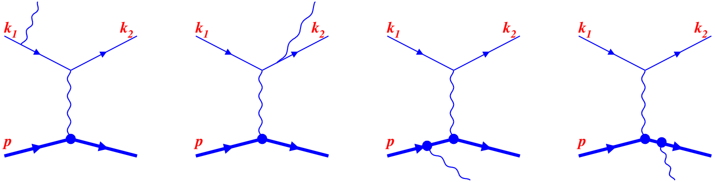
Contribution of additional virtual particles calculated exactly or in ultrarelativistic approximation

For real photon emission only soft part is estimated.

L. C. Maximon and J. A. Tjon Phys. Rev. C **62**, 054320 (2000)

N. Kaiser J. Phys. G **37**, 115005 (2010)

E. A. Kuraev, V. V. Bytev, S. Bakmaev and E. Tomasi-Gustafsson, Phys. Rev. C **78**, 015205 (2008)



$ie\gamma_\mu$ – electron-photon vertex

$-ie\left[\gamma_\mu F_d(q^2) + \frac{i\sigma_{\alpha\mu}q^\mu}{2M}F_p(q^2)\right]$ – proton-photon vertex

$q = p' - p,\ p^2 = p'^2 = M,\ \tau = Q^2/4M^2,\ Q^2 = -q^2$

$$F_d(q^2) = \frac{G_E(q^2) + \tau G_M(q^2)}{1+\tau},\ F_p(q^2) = \frac{G_M(q^2) - G_E(q^2)}{1+\tau},$$

$$J^{\mu\alpha} \sim \underbrace{\left[\frac{k_1^\alpha}{kk_1} - \frac{k_2^\alpha}{kk_2}\right]\gamma^\mu}_{\text{Soft part}} - \frac{\gamma^\mu\hat{k}\gamma^\alpha}{2kk_1} - \frac{\gamma^\alpha\hat{k}\gamma^\mu}{2kk_2}$$ – BH current

$e(k_1)+p(p)\to e(k_2)+p(p')+\gamma(k)$

$$d\sigma_i = \frac{1}{2\sqrt{S^2-4M_p^2m_l^2}}\left(\mathcal{M}_{BH}\mathcal{M}_h^\dagger + \mathcal{M}_h\mathcal{M}_{BH}^\dagger\right)d\Gamma$$

$$d\Gamma = \frac{dQ^2dvdtd\phi_k}{2^8\pi^4\sqrt{S^2-4M_p^2m_l^2}\sqrt{Q^2(Q^2+4M^2)}}$$

$S=2k_1p,\ Q^2=-q^2=-(k_1-k_2)^2,\ t=-(q-k)^2=-(p-p')^2$

$v=(p+q)^2-M^2$ – inelasticity

ϕ_k angle between $(\vec{q},\vec{k})$ and $(\vec{k_1},\vec{k_2})$ for $p=(M,0,0,0)$

Infrared free part

$$d\sigma_i^F = d\sigma_i - d\sigma_i^{IR} = \int_0^{v_{cut}} dv \sum_{i,j,k=d,p}\theta_{ijk}F_i(Q^2)F_j(t)F_k(0)$$

$$0<v_{cut}<v_{max}=S-Q^2-\frac{M^2Q^2}{S}$$

$$\frac{d\sigma_i^{IR}}{dQ^2} = \frac{\alpha}{\pi}\left[\int_0^{\bar{v}} dv F_{IR} + \int_{\bar{v}}^{v_{cut}} dv F_{IR}\right] F_d(0)\frac{d\sigma_{el}}{dQ^2} = \frac{\alpha}{\pi}(\delta_S + \delta_H) F_d(0)\frac{d\sigma_{el}}{dQ^2}$$

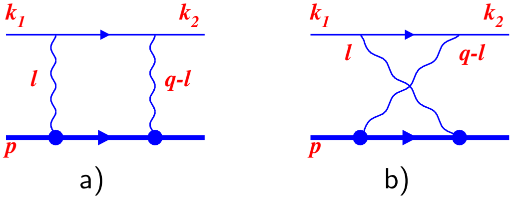
$$\bar{v} \ll m_l, M_p, S, Q^2$$

$$F_{IR} = \int \frac{dt d\phi_k}{4}\left[\frac{S}{(k_2k)(p_2k)} + \frac{S}{(k_1k)(p_1k)} - \frac{S-Q^2}{(k_1k)(p_2k)} - \frac{S-Q^2}{(k_2k)(p_1k)}\right]$$

$$\delta_S = \delta_S^1 - 2(SL_S - X_0L_{X0})\log\left[\frac{\bar{v}}{M_p\lambda}\right],\ L_S = \frac{1}{\sqrt{S^2-4M_p^2m_l^2}}\log\frac{S+\sqrt{S^2-4M_p^2m_l^2}}{S-\sqrt{S^2-4M_p^2m_l^2}}$$

$$\delta_H = \delta_H^1 - 2(SL_S - X_0L_{X0})\log\left[\frac{v_{cut}}{\bar{v}}\right], L_{X0} = \frac{1}{\sqrt{X_0^2-4M_p^2m_l^2}}\log\frac{X_0+\sqrt{X_0^2-4M_p^2m_l^2}}{X_0-\sqrt{X_0^2-4M_p^2m_l^2}}$$

$$X_0 = S - Q^2$$

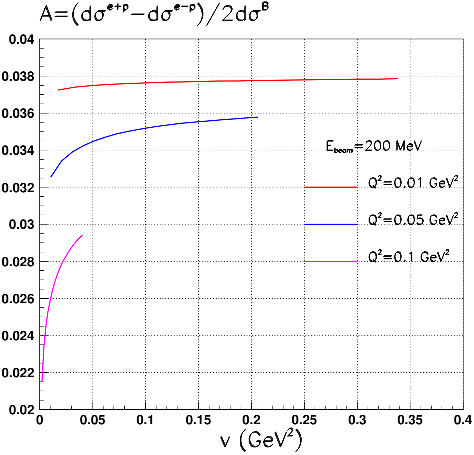


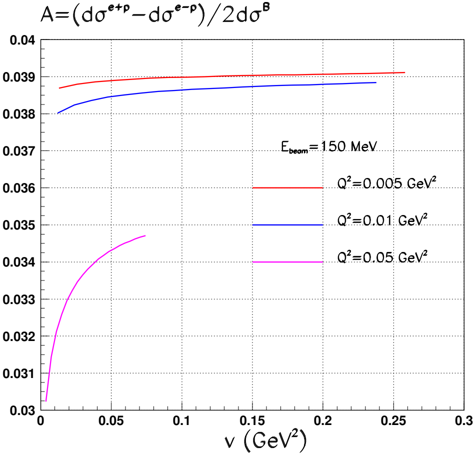
$$\frac{d\sigma_{2\gamma}}{dQ^2} = \frac{1}{16\pi S}\int \frac{d^4 l}{(2\pi)^4}\left[\mathcal{M}_a\mathcal{M}_{el}^\dagger + \mathcal{M}_{el}\mathcal{M}_a^\dagger + \mathcal{M}_b\mathcal{M}_{el}^\dagger + \mathcal{M}_{el}\mathcal{M}_b^\dagger\right]$$

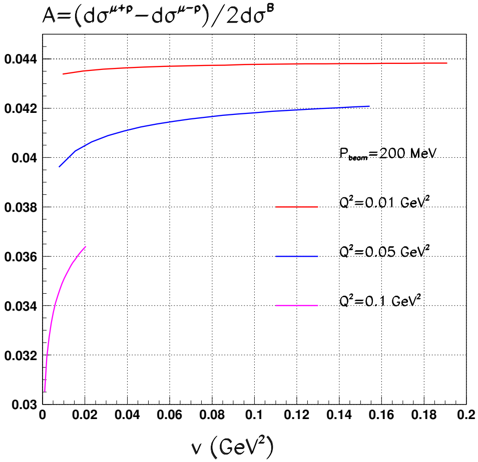
Take into account only infrared divergence part i.e. $l \to 0, q$

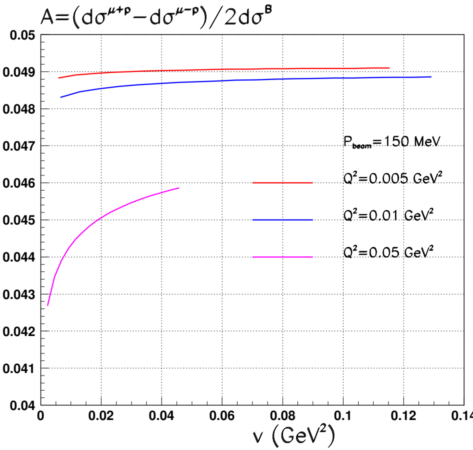
$$\frac{d\sigma_{2\gamma}^{IR}}{dQ^2} = \frac{\alpha}{\pi}\left(\delta_{2\gamma}^1 + (SL_S - X_0 L_{X0})\log\left[\frac{Q^2}{\lambda^2}\right]\right) F_d(0)\frac{d\sigma_{el}}{dQ^2}$$

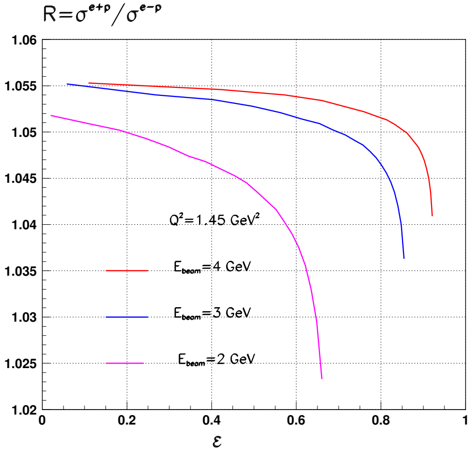
The sum $\frac{d\sigma_i^{IR}}{dQ^2} + \frac{d\sigma_{2\gamma}^{IR}}{dQ^2}$ are infrared free


A=(dσ^e+p − dσ^e−p)/2dσ^B
E_beam=200 MeV
Q²=0.01 GeV²
Q²=0.05 GeV²
Q²=0.1 GeV²
v (GeV²)
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4


A=(dσ^e+p − dσ^e−p)/2dσ^B
E_beam=150 MeV
Q²=0.005 GeV²
Q²=0.01 GeV²
Q²=0.05 GeV²
v (GeV²)
0.04
0.039
0.038
0.037
0.036
0.035
0.034
0.033
0.032
0.031
0.03
0
0.05
0.1
0.15
0.2
0.25
0.3


A=(dσ^{μ+p}−dσ^{μ−p})/2dσ^B
P_beam=200 MeV
Q²=0.01 GeV²
Q²=0.05 GeV²
Q²=0.1 GeV²
ν (GeV²)
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2


A=(dσ^{μ+p}−dσ^{μ−p})/2dσ^B
P_beam=150 MeV
Q²=0.005 GeV²
Q²=0.01 GeV²
Q²=0.05 GeV²
ν (GeV²)
0.05
0.049
0.048
0.047
0.046
0.045
0.044
0.043
0.042
0.041
0.04
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14



$$\varepsilon^{-1} = 1 + 2(1+\tau)\tan^2\frac{\theta}{2}$$

- Influence of hard photon emission on charge asymmetry in lepton-proton scattering has been estimated for the first time beyond the ultrarelativistic limit keeping lepton mass during the whole process of calculation.
- Numerical result shown that at the fixed lepton energy the dependence of charge asymmetry on hard photon emission more essential at high Q^2.
- The next step consists in the implementation of the obtained results into Monte-Carlo generator ELRADGEN for simulation of hard photon emission.