The lowest order radiative corrections to the lepton current in polarized SIDIS

A. Ilyichev
Institute for Nuclear Problems, Byelorussian State University, Minsk Belarus

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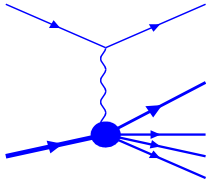
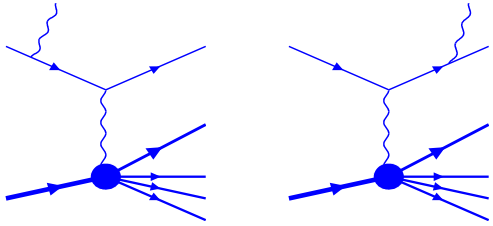
Contribution to the lowest-order RC in SiDIS $ep \to ehX$

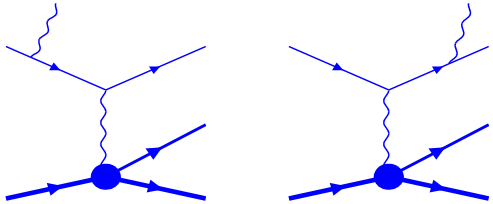
- The lowest order contribution.



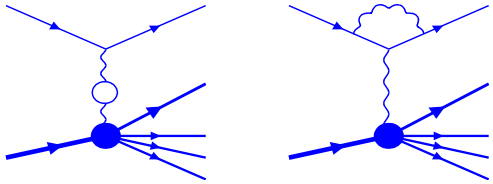
- Real photon emission from lepton line with the inelastic final hadronic state. Contains the infrared divergence.



- Real photon emission from lepton line with the exclusive final hadronic state. Infrared free.



- Additional virtual particle contribution. Last graph contains the infrared divergence.



Advantages of Model-Independent RC

- The task can be solved exactly.
- Model-Independent RC is rather large because of including so-called leading-order term $\log(Q^2/m^2)$.
- Uncertainties of the model-independent RC come only from fits and models used for structure functions.
- The calculation of model-dependent correction (box-type graphs, real photon emission from hadronic line) requires additional assumptions about hadron interaction, so it has additional pure theoretical uncertainties, which are hard to control.

RC without exclusive radiative tail

- RC to unpolarized three-fold cross section $\frac{d\sigma}{dxdydz}$

  A.V. Soroko, N.M. Shumeiko. Sov.J.Nucl.Phys. 49 (1989) 838-844,
  Yad.Fiz. 49 (1989) 1348-1358

- RC to polarized three-fold cross section $\frac{d\sigma}{dxdydz}$

  A.V. Soroko, N.M. Shumeiko. Sov.J.Nucl.Phys. 53 (1991) 628-631
  Yad.Fiz. 53 (1991) 1015-1020

  as an option SIRAD of FORTRAN code POLRAD 2.0

  I.Akushevich, et al. Comp.Phys.Comm. 104 (1997) 201-244

- RC to unpolarized five-fold cross section $\frac{d\sigma}{dxdydzd\phi_h dp_T}$

  I.Akushevich, N.Shumeiko, A.Soroko. Eur.Phys.J. C10 (1999) 681-687

  Basing on this calculation FORTRAN code HAPRAD has been developed.

RC with exclusive radiative tail

- Exclusive radiative tail contribution to unpolarized five-fold cross section $\frac{d\sigma}{dxdydzd\phi_h dp_T}$

  I.Akushevich, A.Ilyichev, M.Osipenko. Eur.Phys.J. C10 (1999) 681-687

  has been included in FORTRAN code HAPRAD. As it will be shown later, in some kinematical region this contribution is rather important.

Hadronic tensor for SIDIS

One of the important thing for the numerical estimation of model-independent RC consists in the knowledge of the hadronic tensor structure as well as the structure function parameterization in the rather wide kinematical region both for SiDIS and exclusive final hadronic states.

According to Aram Kotzinian. Nucl.Phys. B441 (1995) 234-248 the hadronic tensor for SiDIS with the initial polarized nucleon reads

$$W_{\mu\nu} = \sum_{a,b=0}^{3} e_{\mu}^{\gamma(a)} e_{\nu}^{\gamma(b)} (H_{ab}^{(0)} + \sum_{\rho,i=0}^{3} s^{\rho} e_{\rho}^{h(i)} H_{abi}^{(S)}).$$

$e^{\gamma(a,b)}$ ($e^{h(i)}$) are the complete set of the basis vectors for the polarization 4-vectors of the virtual photon (nucleon) in the target rest frame.
Due to the parity and current conservation, hermiticity as well as $ps \equiv 0$, only 5 spin-independent $H_{ab}^{(0)}$ and 13 spin-dependent $H_{abi}^{(S)}$ SF are survived. All the rest of the SF have to be set to zero.
Another set of SF can be found in A. Bacchetta et al. JHEP 0702 (2007) 093

Exclusive radiative tail

Exclusive radiative tail contribution $d\sigma_R^{ex} \sim W_{ex}^{\mu\nu} L_{\mu\nu}^R d\Gamma_R^{ex}$,

Hadronic tensor: $W_{ex}^{\mu\nu} \sim \mathcal{M}^\mu \mathcal{M}^{\nu\dagger}$, $\mathcal{M}^\mu = \bar{u}(p_f)\left(\sum_{i=1}^6 A_i M_i^\mu\right) u(p_i)$

$$M_1^\mu = -\frac{i}{2}\gamma_5\left(\gamma^\mu \not{k} - \not{k}\gamma^\mu\right),$$

$$M_2^\mu = 2i\gamma_5\left[P^\mu k\cdot\left(q - \frac{1}{2}k\right) - \left(q^\mu - \frac{1}{2}k^\mu\right)k\cdot P\right],$$

$$M_3^\mu = -i\gamma_5\left(\gamma^\mu k\cdot q - \not{k}q^\mu\right),$$

$$M_4^\mu = -2i\gamma_5\left(\gamma^\mu k\cdot P - \not{k}P^\mu\right) - 2m_N M_1^\mu,$$

$$M_5^\mu = i\gamma_5\left(k^\mu k\cdot q - q^\mu k^2\right),$$

$$M_6^\mu = -i\gamma_5\left(\not{k}k^\mu - \gamma^\mu k^2\right).$$

Six invariant amplitudes A_i can be extract from MAID 2007.

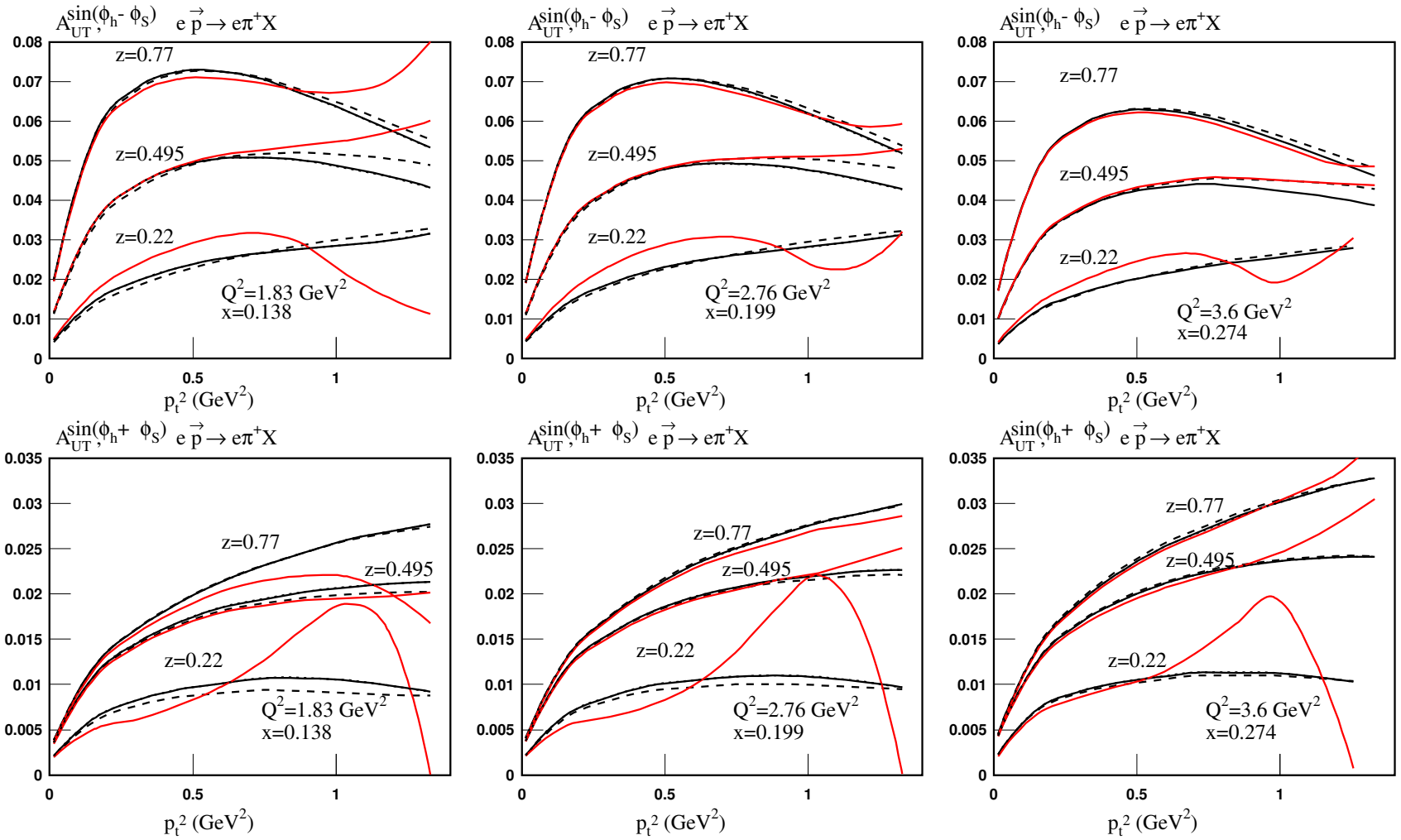
Collins and Sivers asymmetries

$$A_{UT}^{\sin(\phi_h-\phi_S)} = \frac{\int_0^{2\pi} d\phi_S \int_0^{2\pi} d\phi_h \sin(\phi_h - \phi_S)\sigma^{UT}}{\int_0^{2\pi} d\phi_S \int_0^{2\pi} d\phi_h \sigma^{UT}}$$

$$A_{UT}^{\sin(\phi_h+\phi_S)} = \frac{\int_0^{2\pi} d\phi_S \int_0^{2\pi} d\phi_h \sin(\phi_h + \phi_S)\sigma^{UT}}{\int_0^{2\pi} d\phi_S \int_0^{2\pi} d\phi_h \sigma^{UT}}$$

where ϕ_h (ϕ_S) is azimuthal angle of the detected hadron (the transverse part of the nucleon polarized vector).

RC to Collins and Sivers asymmetries
Preliminary results



Conclusions

- Basing on Aram's expression we construct the hadronic tensor in the covariant form

$$W_{\mu\nu} = -g^{\perp}_{\mu\nu}\mathcal{H}_1 + p^{\perp}_{\mu}p^{\perp}_{\nu}\mathcal{H}_2 + p^{\perp}_{h\mu}p^{\perp}_{h\nu}\mathcal{H}_3 + (p^{\perp}_{\mu}p^{\perp}_{h\nu} + p^{\perp}_{h\mu}p^{\perp}_{\nu})\mathcal{H}_4$$

$$+i(p^{\perp}_{\mu}p^{\perp}_{h\nu} - p^{\perp}_{h\mu}p^{\perp}_{\nu})\mathcal{H}_5 + (p^{\perp}_{\mu}n_{\nu} + n_{\mu}p^{\perp}_{\nu})\mathcal{H}_6 + i(p^{\perp}_{\mu}n_{\nu} - n_{\mu}p^{\perp}_{\nu})\mathcal{H}_7$$

$$+(p^{\perp}_{h\mu}n_{\nu} + n_{\mu}p^{\perp}_{h\nu})\mathcal{H}_8 + i(p^{\perp}_{h\mu}n_{\nu} - n_{\mu}p^{\perp}_{h\nu})\mathcal{H}_9.$$

$g^{\perp}_{\mu\nu} = g_{\mu\nu} - q_{\mu}q_{\nu}/q^2$ $p^{\perp}_{\mu} = p_{\mu} - q_{\mu}pq/q^2$ and
$n^{\mu} = \varepsilon^{\mu\nu\rho\sigma}q_{\nu}p_{\rho}p_{h\sigma}$
with 9 generalized SF $\mathcal{H}_{1-9}$ and found that the born cross section exactly reproduced the cross section obtained by Alessandro Bacchetta.

- Using Bardin-Shumeiko approach we obtained the analytical expressions for the lowest order model-independent RC to polarized SiDIS. These expressions are written in the most compact, covariant form convenient for the numerical analysis.

Conclusions

- The obtained above results have been published in I.Akushevich, A.Ilyichev. Phys.Rev. D100 (2019) no.3, 033005
- More than two year ago using WW-SIDIS model for the structure functions
  S. Bastami *et al.*, JHEP **1906**, 007 (2019)
  we start to develop the new version of FORTRAN code HAPRAD that allows to calculate RC to polarized SiDIS coming from the inelastic final hadronic state.
- The lowest order radiative corrections to the lepton current in polarized SIDIS for Sivers and Collins asymmetries shown rather essential contribution in the regions small z and large p_t from exclusive radiative tail that was estimated with the help of 6 invariant amplitudes A_i in MAID 2007 model.