EPRC: A Program Package for Electroweak Physics at HERA

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Abstract: I describe a collection of programs and subroutines for the calculation of cross sections for neutral and charged current deep inelastic lepton proton scattering at HERA including electroweak radiative corrections.

1 Introduction

The program package EPRC is the result of a development which started in 1986 with the calculation of the complete electroweak radiative corrections for deep inelastic electron proton scattering at HERA [1]. It was used during several workshops on HERA physics [2, 3] and continuously improved according to requests from many users. Major modifications have led to the development of the program `eprc93.f` which was used for the calculations published in [4]. Extensive use of this package also during the present workshop seems to justify the publication of a short description of it in these proceedings.

The purpose of EPRC is to assist in studies focussing on electroweak physics at HERA which do not require to rely on predictions which take into account QED and QCD higher-order effects in a most sophisticated way. Programs in EPRC either do not take into account purely photonic corrections or they take them into account in the leading logarithmic approximation. A separation of $O(\alpha)$ corrections into purely photonic and purely weak contributions is sensible for two reasons: First, QED corrections are very sensitive to kinematical cuts and details of the experimental selection criteria; therefore these corrections are usually applied directly to the data. Second, the cross section including purely weak corrections is sufficient to study the dependence on parameters of the electroweak standard model. Therefore the programs of EPRC have proved valuable tools in studying the sensitivity of deep inelastic scattering cross sections on standard model parameters and on neutral current couplings of quarks [5].

For a confrontation of experimental data with theoretical predictions, QED corrections are indispensable. The Monte Carlo event generator HERACLES [6] is a flexible tool which can be used for this purpose. Concerning the purely weak radiative corrections of order $O(\alpha)$, EPRC and HERACLES take into account the same physics; EPRC provides a few additional features with respect to higher-order corrections of order $O(\alpha^2)$. Studies of higher-order QCD effects can be performed with the help of DJANGO6 [7] which interfaces HERACLES to LEPTO [8]; moreover, there is a large number of special purpose programs suited for the investigation of QCD phenomena.

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2 Standard Model Predictions for Deep Inelastic Scattering

2.1 Lowest Order Cross Sections

Deep inelastic scattering of electrons or positrons off protons

$$e(l) + p(p) \to e'(l') + X(p_X), \tag{1}$$

with $e' = e$ for neutral current scattering (NC) and $e' = \nu_e$ $(\bar{\nu}_e)$ for charged current scattering (CC) (particle momenta are given in parentheses) is usually described by the following set of kinematic variables

$$Q^2 = -(l - l')^2, \quad s = (l + p)^2, \quad x = \frac{Q^2}{2p \cdot (l - l')}, \quad y = \frac{Q^2}{xs}. \tag{2}$$

In the region of large x and Q^2 where the contribution of the longitudinal structure function F_L and proton mass effects can be neglected, the differential cross section for the neutral current process for left-handed (L) and right-handed (R) polarized electrons is given by

$$\frac{d^2\sigma^{NC}}{dx\, dQ^2}(e^-_{L,R}) = \frac{2\pi\alpha^2}{xQ^4} \left[\left(1 + (1-y)^2\right) F_2^{L,R} + \left(1 - (1-y)^2\right) xF_3^{L,R}\right]. \tag{3}$$

For positron scattering one has to replace $F_3^{L,R} \to -F_3^{R,L}$ and cross sections for beams with an arbitrary degree of longitudinal polarization P can be obtained by calculating the appropriate average of the cross sections for left- and right-handed leptons. In the quark-parton model, the structure functions are expressed in terms of quark (q) and antiquark ($\bar{q}$) distribution functions:

$$\begin{aligned} F_2^{L,R} &= \sum_q [xq(x,Q^2) + x\bar{q}(x,Q^2)] \cdot A_q^{L,R}, \\ xF_3^{L,R} &= \sum_q [xq(x,Q^2) - x\bar{q}(x,Q^2)] \cdot B_q^{L,R}. \end{aligned} \tag{4}$$

By using Q^2-dependent parton distribution functions, QCD corrections are taken into account automatically in the leading-logarithmic approximation. The coefficients $A_q^{L,R}$ and $B_q^{L,R}$ contain coupling constants and propagators corresponding to photon and Z-boson exchange ($L \leftrightarrow +$, $R \leftrightarrow -$):

$$\begin{aligned} A_q^{L,R} &= Q_q^2 + 2Q_e Q_q (v_e \pm a_e) v_q \chi_Z + (v_e \pm a_e)^2 (v_q^2 + a_q^2) (\chi_Z)^2, \\ B_q^{L,R} &= \pm 2Q_e Q_q (v_e \pm a_e) a_q \chi_Z \pm 2(v_e \pm a_e)^2 v_q a_q (\chi_Z)^2, \end{aligned} \tag{5}$$

with

$$\chi_Z = N_Z^{(0)} \frac{Q^2}{Q^2 + m_Z^2} \tag{6}$$

and a normalization constant $N_Z^{(0)}$ which, in lowest order, can be expressed either with the help of the weak mixing angle or with the help of the μ decay constant, G_μ:

$$N_Z^{(0)} = \frac{1}{4s_W^2 c_W^2} = \frac{\sqrt{2} G_\mu m_Z^2}{4\pi\alpha}. \tag{7}$$

In the standard model, the couplings of the fermions to the bosons are given by the electric charge (in units of e) for the photon exchange and, for the Z-boson exchange, by $(f = e, q)$

$$a_f = I_3^f, \qquad v_f = I_3^f - 2Q_f \sin^2\theta_W \tag{8}$$

where Q_f and I_3^f denote the charge and the third component of the weak isospin of the fermion f. In the standard model with a Higgs doublet, the mixing angle is related to the vector boson masses by

$$\sin^2\theta_W = s_W^2 = 1 - \frac{m_W^2}{m_Z^2}. \tag{9}$$

In a similar way one can write for the charged current differential cross section

$$\frac{d^2\sigma^{CC}}{dx\,dQ^2}(e^-) = (1-P)\pi\alpha^2\left(N_W^{(0)}\right)^2 \cdot \frac{1}{(Q^2+m_W^2)^2}\left[u + c + (1-y)^2(\bar{d}+\bar{s})\right], \tag{10}$$

with, to lowest order,

$$N_W^{(0)} = \frac{1}{2s_W^2} = \frac{G_\mu m_W^2}{\sqrt{2}\pi\alpha}, \tag{11}$$

and P denoting the degree of left-handed longitudinal polarization ($P = -1$ for left-handed electrons, $P = 1$ for right-handed electrons). For positron scattering one has to replace $u + c \to \bar{u} + \bar{c}$ and $\bar{d} + \bar{s} \to d + s$ and adjust the sign of P.

2.2 Higher-Order Corrections

Since the program package EPRC is devoted to studies of electroweak physics at HERA, we do not discuss QED corrections which are large and indispensable, in particular for NC scattering at small x and large y. Purely photonic corrections have been discussed extensively in [9] where the interested reader will also find short descriptions of and references to programs for their calculation. QCD corrections are also not discussed here. They should, of course, be included in order to obtain reliable predictions.

The calculations of higher-order electroweak corrections to deep inelastic scattering at HERA have been reviewed in [9, 10] (see also references therein). They are performed in the on-shell scheme, where the gauge boson masses m_W and m_Z are treated symmetrically as basic parameters together with the top quark mass m_t and the Higgs mass m_H (besides the fine structure constant α and other fermion masses). Amplitudes are functions of these basic parameters.

According to this scheme, a natural way to fix the standard model parameters is to choose values for m_W, m_Z, besides m_t and m_H. In view of the fact that there is a high precision measurement of the μ-decay constant G_μ, it is, however, useful and customary to consider the situation where a value for m_W is derived from G_μ after fixing the other mass parameters. Accordingly, the normalization of the Z and W exchange amplitudes can be expressed in different ways as indicated in Eqs. (7) and (11). When taking into account the generic higher-order corrections to these amplitudes, one has also to take into account higher-order corrections to the μ-decay constant when switching from one prescription to the other in order to be consistent.

The corrections are collected in form factors that change the amplitudes in a simple form: the dressed photon-exchange amplitude can be written in the following way:

$$\mathcal{M}_\gamma = \frac{e^2}{1-\hat{\Pi}^\gamma_f(Q^2)} \cdot \frac{1}{Q^2} \cdot Q_e \gamma_\mu \otimes Q_f \gamma^\mu . \tag{12}$$

$\hat{\Pi}^\gamma_f$ is the fermionic part of the photon vacuum polarization. Writing it in the denominator resums the leading logarithmic corrections according to the renormalization group equation and the first factor in Eq. (12) constitutes the running fine structure constant $\alpha_{em}(Q^2)$. $\hat{\Pi}^\gamma_f$ contains hadronic contributions taken into account by using a parametrization derived from data on the total hadronic cross section in e^+e^- annihilation [11]. Bosonic contributions to the vacuum polarization have to be combined with vertex and box corrections and are added as a separate correction term.

The weak one-loop corrections to the Z-exchange amplitude, $\mathcal{M}_Z$, for $eq \to eq$ can be expressed in terms of four weak form factors (ρ_{eq}, κ_e, κ_q, and κ_{eq}) in the following way, making use of dressed vector couplings:

$$\begin{aligned}\mathcal{M}_Z(\hat{s},Q^2) \sim \frac{\pi\alpha}{Q^2+m_Z^2} N_Z^{(1)} \Big[& I_3^e I_3^q \gamma_\mu\gamma_5 \otimes \gamma_\mu\gamma_5 + \bar{v}_e I_3^q \gamma_\mu \otimes \gamma_\mu\gamma_5 \\ & + I_3^e \bar{v}_q \gamma_\mu\gamma_5 \otimes \gamma^\mu + \bar{v}_{eq}\gamma_\mu \otimes \gamma^\mu \Big],\end{aligned} \tag{13}$$

$$\bar{v}_f = I_3^f \left[1 - 4|Q_f| s_W^2 \, \kappa_f(\hat{s},Q^2)\right], \quad f = e, q \, , \tag{14}$$

$$\bar{v}_{eq} = I_3^e \bar{v}_q + \bar{v}_e I_3^q - I_3^e I_3^q \left[1 - 16|Q_e Q_q| s_W^4 \, \kappa_{eq}(\hat{s},Q^2)\right], \tag{15}$$

with $\hat{s} = xs$ and s_W^2 from Eq. (9). The normalization of the Z-exchange amplitude is modified at $O(\alpha)$ by a form factor $\rho_{eq}(\hat{s},Q^2)$:

$$N_Z^{(1)} = \frac{\sqrt{2}G_\mu m_Z^2}{4\pi\alpha}\rho_{eq}(\hat{s},Q^2) = \frac{1}{4s_W^2c_W^2}\frac{\rho_{eq}(\hat{s},Q^2)}{1-\Delta r}. \tag{16}$$

The second form of the normalization factor is used when m_W and m_Z (and thus s_W^2) is given as input. It follows when using the G_μ constraint with consistent inclusion of radiative corrections to the μ decay:

$$G_\mu = \frac{\pi\alpha}{\sqrt{2}s_W^2 m_W^2}\frac{1}{1-\Delta r(\alpha, m_W, m_Z, m_H, m_t)} \tag{17}$$

In the Born approximation, $\rho = \kappa = 1$, and $\bar{v}_{eq} = v_e v_q$. The above parametrization has the form of a Born-like expression except that at the Born level there is no parallel for the coupling $\bar{v}_{eq}$. The axial-vector couplings can be kept in their form $a_f = I_3^f$ by absorbing corresponding vertex corrections into the normalization factor $\rho_{eq} = \rho_{eq}(\hat{s},Q^2)$ which receives also contributions from self energies. The form factors κ_f and κ_{eq} combined with s_W^2 give rise to effective mixing angles which depend through the κ's on the fermion species and on the kinematic variables. The form factors can be separated into a universal part independent of the fermion species and a non-universal remainder term. The universal parts contain the dependence on the masses of the top quark and the Higgs boson. The dominating contribution to them is proportional to m_t^2 and with

$$\Delta\rho = \frac{3\alpha}{16\pi s_W^2 c_W^2}\frac{m_t^2}{m_Z^2} \tag{18}$$

one has to one-loop precision

$$\rho_{eq} = 1 + \Delta\rho + \Delta\rho_{eq}^{rem}, \tag{19}$$

$$\kappa_f = 1 + \frac{c_W^2}{s_W^2}\Delta\rho + \Delta\kappa_f^{rem}. \tag{20}$$

Resummation of higher-order terms can be performed by the replacements

$$\rho_{eq} \to \frac{1+\Delta\rho_{eq}^{rem}}{1-\Delta\bar{\rho}}, \tag{21}$$

$$\kappa_f \to (1+\Delta\kappa_f^{rem})\left(1+\frac{c_W^2}{s_W^2}\Delta\bar{\rho}\right), \tag{22}$$

$$\kappa_{eq} \to (1+\Delta\kappa_{eq}^{rem})\left(1+\frac{c_W^2}{s_W^2}\Delta\bar{\rho}\right)^2. \tag{23}$$

Here, $\Delta\bar{\rho}$ contains irreducible two-loop contributions and is defined by

$$\Delta\overline{\rho} = 3\,\frac{G_\mu m_t^2}{8\pi^2\sqrt{2}} \cdot \left[1 + \frac{G_\mu m_t^2}{8\pi^2\sqrt{2}} \cdot r_2\right] + \Delta\rho^{\alpha\alpha_s}. \tag{24}$$

In our calculation we use for r_2 the result of [12] with the full two-loop m_H-dependence. The leading correction of $\mathcal{O}(\alpha\alpha_s)$ is given by

$$\Delta\rho^{\alpha\alpha_s} = -\Delta\rho\frac{\alpha_s(m_t^2)}{\pi}\cdot\frac{2}{3}\left(\frac{\pi^2}{3}+1\right) \tag{25}$$

with $\Delta\rho$ from Eq. (18). To $O(\alpha)$, $\Delta\overline{\rho}$ is equal to $\Delta\rho$. The remainder terms (index rem) are the one-loop expressions with the corresponding leading m_t^2 terms subtracted. More details and references to the original literature can be found in [10].

It should be stressed that the form factors are functions of the kinematic variables x and Q^2 and depend on the fermion species. The x-dependence is due to box diagram contributions which also lead to $\rho_{eq} \neq \rho_{e\bar{q}}$. Since the measurement of deep inelastic cross sections covers a large range of x and Q^2, this dependence which is as large as the constant m_t^2 terms cannot be neglected if a precision of few percent is needed (LEP1 measurements are, in contrast to this, performed at a fixed $Q^2 = -m_Z^2$).

The W-exchange amplitude including higher-order contributions can be written in the following way:

$$\mathcal{M}_W(\hat{s},Q^2) = \frac{\pi\alpha}{4}\,N_W^{(1)}\frac{1}{Q^2+m_W^2}\,\gamma_\mu\,[1-\gamma_5]\otimes\gamma^\mu\,[1-\gamma_5] \tag{26}$$

with

$$N_W^{(1)} = \frac{G_\mu m_W^2}{\sqrt{2}\pi\alpha}\,\rho_{eq}^W(\hat{s},Q^2) = \frac{1}{2s_W^2}\frac{\rho_{eq}^W(\hat{s},Q^2)}{1-\Delta r}. \tag{27}$$

Differently from the neutral current, only a single form factor ρ_{eq}^W (or $\rho_{e\bar{q}}^W$) for each parton scattering process is required to accommodate the higher-order contributions. In the representation with fixed G_μ, the weak radiative corrections are very small with very little dependence on m_t and m_H and we have

$$\rho_{eq}^W \equiv (\rho_{eq}^W)^{rem} \tag{28}$$

which deviates from 1 typically by a few permille.

3 Description of program elements

This section gives an overview over the programs contained in the package EPRC. The recommended part of this library is the program contained in `eprc93.f` which allows the calculation of total cross sections and includes the complete electroweak loop corrections as described in the previous section. Other programs are designed for the calculation of Born cross sections, of purely weak corrections, or of leptonic QED corrections in the leading logarithmic approximation (LLA) of order $O(\alpha)$ or $O(\alpha^2)$ [13]. For the charged current process, the program `epcctot.f` contains an option to include soft photon exponentiation. In addition there are programs for deep inelastic scattering with polarized leptons and protons and for radiative charged current scattering.

The programs contained in this dataset are based on analytic calculations or on numerical integration methods which do not need too much CPU-time. Monte Carlo methods are only partly used for numerical integration, but no Monte Carlo event generator is contained in this dataset. The programs `epnctot.f` and `epcctot.f` contain the complete photonic corrections. Their use is, however, not particularly recommended since they provide results for the twofold differential cross sections only and need a rather large amount of CPU-time while not always giving results with high numerical precision. These programs call subroutines using `REAL*16` variables which is not supported on many existing computers.

Further helpful information can be found in the files `aacommon.doc` (definition of common blocks used in the programs), `aapdfs.doc` (convention for calls of parton distribution functions, see below) and `aalpar.doc` (conventions and recommendations for the steering parameters `LPAR`, see section 4). Future modifications and updates (after 28 July 1991) will be announced in the file `aaupdate.doc`. Additional files not mentioned in this description exist in the package, containing programs for specific test purposes. They should be used only by experienced users. Some of the programs have to be linked with the CERN library or the NAG library (for integration routines) as indicated by a corresponding comment in the files.

1.) Born cross sections

- `epncborn.f` Lowest order cross section $d^2\sigma/dxdy$ for deep inelastic neutral current electron (positron) proton scattering at HERA.
- `epccborn.f` Lowest order cross section $d^2\sigma/dxdy$ for deep inelastic charged current electron (positron) proton scattering at HERA.
- `epncasym.f` Lowest order results for the polarization and charge asymmetries in NC DIS ep scattering at HERA for twofold differential cross sections $d^2\sigma/dxdy$.

2.) Weak corrections and improved Born cross sections

- `formff.f` Program for the calculation of Δr, the (universal) effective weak mixing angle and the running fine structure constant $\alpha(Q^2)$.
- `epncweak.f` The improved Born cross section for neutral current scattering, including weak loop corrections and vacuum polarization.
- `epccweak.f` The improved Born cross section for charged current scattering, including weak loop corrections, vacuum polarization and some remnant parts of QED corrections.

`eprc93.f` Stand-alone version of a program to calculate neutral and charged current total cross sections and their ratio as well as polarization and charge asymmetries. This program includes the complete weak loop corrections, but QED corrections only in the leading logarithmic approximation. It allows the inclusion of non-standard contributions to the gauge boson self energies (S, T, U parameters, for details see [4]). Cuts on x, y, Q^2 and p_T, determined by the momentum of the scattered lepton, are possible. A sample output is stored in the file `eprc93.dat`.

`eprc93q.f` Same as `eprc93.f`, but for the single-differential cross section $d\sigma/dQ^2$.

`eprc93xy.f` Same as `eprc93.f`, but for twofold differential cross sections $d^2\sigma/dxdy$.

`zncvs.f` Contains subroutines for the calculation of the Born cross section, soft bremsstrahlung and electroweak virtual corrections. Contains also the initialization subroutine `SETPAR`.

`zccvs.f` Contains the additional subroutines for Born cross section, soft bremsstrahlung, and virtual corrections for the charged current process.

3.) Leading-log programs

`epncllas.f` Leptonic corrections of order $O(\alpha)$ in the leading logarithmic approximation including complete electroweak one-loop corrections.

`epccllas.f` The same for the charged current.

`epnclla2.f` Program for the calculation of leptonic corrections of order $O(\alpha^2)$ in the leading logarithmic approximation [13].

`zeplla.f` Routines for the calculation of leading logarithmic corrections (leptonic legs) to one- and two-loop order and the corrected cross sections for NC and CC scattering.

4.) Total cross sections including hard bremsstrahlung

`epnctot.f` The total electroweak corrections for the neutral current cross section.

`epcctot.f` The total electroweak corrections for the charged current cross section. Only for electron scattering, but with the option to exponentiate soft-photon corrections.

`znchbst.f16` Contains routines for the calculation of hard bremsstrahlung contributions to the total corrections in neutral current scattering. These routines are needed in `epnctot.f`.

`zcchbst.f16` Contains routines for the calculation of hard bremsstrahlung contributions to the total corrections in charged current scattering. These routines are needed in `epcctot.f`.

5.) Integrated cross sections

`zsigint.f` Routines for the calculation of integrated cross sections for NC and CC scattering. Integration can be performed over kinematical ranges defined with the help of upper and lower cuts on x, y, Q^2 and p_T (the transverse momentum of the electron). Virtual corrections and the leptonic leading logarithmic corrections can be included.

`zpdfint.f` Routine to obtain integrated parton distributions.

`zaxohs.f` The AXO library for integration and event sampling containing a modified version of the integration routine `VEGAS`. Used in programs for total cross sections which take into account hard bremsstrahlung corrections.

6.) Parton distribution functions

`zpver.f`	Interface for calls to parton distribution functions. The conventions for codes of the various parametrizations are described in `aapdfs.doc`.
`zpystfu.f`	Parton distribution functions from `PYTHIA` [14].
`zpdmrsh.f`	Parton distributions from Martin, Roberts and Stirling, set H [15].
`zpdmrsa.f`	Parton distributions from Martin, Roberts and Stirling, set A [16].
`zpdgrv.f`	Parton distributions from Glück, Reya, and Vogt [17].
`zpdgrv94.f`	Parton distributions from Glück, Reya, and Vogt, 1994 update [18].
`zpdcteq3.f`	Parton distributions from the CTeq collaboration, version 3 [19].

7.) Polarized electron nucleon scattering

`epasyp.f`	The cross section for neutral current scattering with polarized electrons and protons including the complete $O(\alpha)$ electroweak and QED corrections. Some sample results are stored in the file `epasyout.dat`.
`epasyn.f`	The same for neutron scattering.
`zncvsa.f`	The same as `zncvs.f` extended to include the case of longitudinal proton polarization. Called from `epasyp.f` and `epasyn.f` .
`znchbsta.f16`	The same as `znchbst.f16` extended to include the case of longitudinal proton polarization. Called from `epasyp.f` and `epasyn.f`.
`zpverap.f`	Polarized parton distribution functions (up and down only) for the calculation of deep inelastic electron proton scattering with polarized protons and electrons. Values are obtained by linear interpolation on a grid of 100 values of x, no Q^2 dependence. Values on the grid points are read from a dataset allocated to unit number 23. These data points are stored in the file `epasyp.dat`. The numbers are from a fit to EMC data (obtained from A. Schäfer).
`zpveran.f`	The same for neutron scattering. Needs input from file `epasyn.dat`.

8.) Radiative charged current scattering

`epccrad.f`	A program for the caluclation of the cross section for radiative charged current scattering $ep \to \nu\gamma X$ including leptonic and quarkonic radiation and its interference. A lower limit on the photon energy is required. The present version is for electron scattering only. A detailed description of the program can be found in the file `aaccrad.doc`.

4 Description of Steering Parameters in EPRC

Most of the steering parameters `LPAR(*)` can be used to study separate contributions to weak one-loop corrections and various options to treat higher-order contributions. They are not options which should be freely used, rather for some of them only one specific choice is recommended or even meaningful. They should be changed with care. If not stated explicitly, a value of 0 means that the given effect is not taken into account. More details and recommendations than given here can be found in the file `aalpar.doc`.

`LPAR(1)`:	=1: include Born cross section;
	=0: used to calculate only one-loop corrections in the NC cross section.
`LPAR(2)`:	=1: include one-loop corrections in NC and CC cross sections;
	=0: no one-loop corrections.

`LPAR(3)`: $=1$: some higher-order corrections are included (soft photon exponentiation in CC, QED corrections applied to improved Born for NC).

`LPAR(4)`: $= 0, 1$: use fixed m_W,
≥ 2: determine m_W from muon decay constant G_μ;
$= 0$: normalize cross sections with the help of s_W^2 from m_W,
≥ 1: normalize cross sections with the help of G_μ;
$= 3$: include Δr in normalization of Z-exchange in NC 'Born' cross section.

`LPAR(5)`: ≥ 1: Δr including one- and leading two-loop contributions;
≥ 2: Δr including corrections of order α_s.

`LPAR(6)`: code for the parametrization of parton densities, see `aapdfs.doc`.

`LPAR(7)`: > 0: include vacuum polarization:
$= 1$: from quark loops with effective quark masses;
$= 2$: hadronic part from Burkhard's parametrization (second reference of [11]);
$= 3$: hadronic part from Jegerlehner's parametrization (first reference of [11]).

`LPAR(8)`: > 0: include photon-Z-mixing.

`LPAR(9)`: > 0: include Z self energy.

`LPAR(10)`: > 0: include W self energy.

`LPAR(11)`: $= 0$: no QED corrections,
≥ 1: include QED corrections.

`LPAR(12)`: > 0: include leptonic QED corrections.

`LPAR(13)`: > 0: include quarkonic QED corrections.

`LPAR(14)`: > 0: include lepton-quark interference (QED).

`LPAR(15)`: > 0: include weak loops.

`LPAR(16)`: > 0: include weak box diagrams.

`LPAR(17)`: photon and/or Z-exchange in NC scattering:
$= 0$: photon and Z-exchange;
$= 1$: only photon exchange;
$= 2$: only photon-Z interference;
$= 3$: only Z-exchange.

`LPAR(18)`: $= 0$: no QED corrections (recommended);
$= 1$: including QED corrections in the leading logarithmic approximation.

`LPAR(19)`: definition of x and y in LLA QED corrections:
$= 1$: x and y defined from scattered lepton momentum;
$= 2$: x and y defined from hadronic final state;
$= 3$: y defined from hadronic final state, Q^2 from scattered electron, $x = Q^2/(ys)$ ('mixed' variables);
$= 4$: y and Q^2 from Jaquet-Blondel method.

`LPAR(20)`: $= 0$: parton distributions with Q^2 as argument;
$= 1$: use fixed external value for Q^2 as argument in parton distributions (given by `FIXQ2E`, for test purposes only).

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