Input parameters and output files of ESEPP

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This document describes the input parameters and the format of output files of the ESEPP event generator [1]. The theoretical basis for the generator is provided in [2] (users of ESEPP are kindly requested to cite this paper). All equation numbers refer to those given in [2].

1 Input parameters

ESEPP is a console application with an interactive command-line interface. The input parameters are entered by a user through an initial dialogue. The requested information includes the items listed below.

- The type of scattering events to generate: e^-p only; e^+p only; both e^-p and e^+p; μ^-p only; μ^+p only; and both μ^-p and μ^+p. There is also an option to additionally generate the purely elastic events in accordance with the Rosenbluth formula (2.4). Such events may be useful to take into account the standard radiative corrections in TPE measurements (see [2], section 3).
- The model to be used to account for the internal structure of the proton. There is a choice between the following models: a point-like proton with magnetic moment μ (so that $G_E \equiv 1$ and $G_M \equiv \mu$); a proton with form factors described by the dipole parametrization (2.9); a proton having form factors in accordance with the Kelly or Puckett parametrizations (see [2], table 2); and a proton whose form factors are described by the parametrization (2.12) with arbitrary values of the coefficients a_{i1}, b_{i1}, b_{i2}, and b_{i3} (they can be specified by a user in the file `const.h`).
- The model to be used to account for first-order bremsstrahlung. A user can choose between the four models described in [2] — the primary, modified, and improved soft-photon approximations, as well as the accurate QED calculation. In the primary soft-photon approximation, only events having purely elastic kinematics are generated, therefore, this option is useful mainly for theoretical analysis and not for real simulation. In each of the four models, one can simulate only lepton bremsstrahlung, only proton bremsstrahlung, or the full effect including the interference between the lepton and proton bremsstrahlung.
- The model to be used to account for the vacuum polarization. A user can choose between three options — taking into account the contribution δ^e_{vac} (2.66) from electron-positron loops only, taking into account the full leptonic contribution $\delta^e_{\text{vac}}+\delta^\mu_{\text{vac}}+\delta^\tau_{\text{vac}}$ (2.71), or taking into account the full vacuum polarization correction δ_{vac} according to the formula (2.74).

- The model to be used to account for the TPE amplitudes. A user can choose whether to use the expressions (2.60) and (2.58) according to the approach of Mo and Tsai or the expressions (2.75) and (2.76) by Maximon and Tjon. In the second case, we take into account the additional contribution $\delta'_{2\gamma}$ (2.77) to the virtual-photon correction δ_{virt}.
- Some kinematic parameters, such as the full energy of the incident lepton, E_ℓ; the cut-off and maximum energies for bremsstrahlung photons, E_γ^{cut} and E_γ^{max} (such that $E_\gamma^{\text{cut}} < E_\gamma < E_\gamma^{\text{max}}$ for inelastic events); the minimum and maximum polar angles of the scattered lepton, θ_ℓ^{min} and θ_ℓ^{max} (such that $\theta_\ell^{\text{min}} < \theta_\ell < \theta_\ell^{\text{max}}$ for all events); and its minimum and maximum azimuthal angles, $\varphi_\ell^{\text{min}}$ and $\varphi_\ell^{\text{max}}$ (such that $\varphi_\ell^{\text{min}} < \varphi_\ell < \varphi_\ell^{\text{max}}$ for all events). It is also possible to choose one of the two commonly used conventions for the azimuthal angles — either $0 \leq \varphi < 2\pi$ or $-\pi < \varphi \leq +\pi$ (in radians).
- Number of events to generate. In the case when $\ell^- p$ and $\ell^+ p$ scattering events are generated together, it is the total number of events of both types. `ESEPP` determines the numbers of events of each type assuming that the integrated luminosities of these processes should be equal. If the purely elastic events in accordance with the Rosenbluth formula are generated additionally, the same rule is used. It is convenient for analysis of TPE measurements (see [2], section 3).
- The format of the output files, including their type (`*.dat` or `*.root`) and names.

2 Output files

Depending on the user choice, the generated events are written to the output files `*.root` or `*.dat`. All output files are located in the same directory where the generator was launched from. Events for the different types of incident leptons are written to separate files — `<pref>_e-.<ext>` for e^-, `<pref>_e+.<ext>` for e^+, `<pref>_mu-.<ext>` for μ^-, and `<pref>_mu+.<ext>` for μ^+. The file extension `<ext>` can be either `root` or `dat`, and the prefix `<pref>` is specified by a user. There is also an option to generate events of purely elastic scattering according to the Rosenbluth formula (2.4), which can be useful for analysis of TPE measurements. These events are written to the file `<pref>_e0.<ext>` (for $e^\pm p$ scattering) or `<pref>_mu0.<ext>` (for $\mu^\pm p$ scattering). Along with the files containing events, a text file `<pref>_e.info` (or `<pref>_mu.info` in the case of $\mu^\pm p$ scattering) is also created in the same directory. It contains a list of the input parameters chosen by a user and some information on the generated events (the numbers of events of different types, integrated cross sections, etc.).

The event files `*.root` are the standard ROOT files containing a tree (an object of the `TTree` class) named `ntp`. This tree has nine branches which correspond to the nine kinematic variables describing the final-state particles, namely E'_ℓ, θ_ℓ, φ_ℓ, E_p, θ_p, φ_p, E_γ, θ_γ, and φ_γ. The names of the branches and their descriptions are given in table 1. The event files `*.dat` are usual text files. Each line of these files represents a single event and contains the same nine kinematic variables written in the same order as they are listed in table 1.

`ESEPP` generates events of two different types — elastic ($\ell^\pm p \to \ell^\pm p$) and inelastic ($\ell^\pm p \to \ell^\pm p\,\gamma$). In order to have a convenient format for the output files, each event

#	Branch	Variable	Description
1	E_l	E'_ℓ, MeV	Full energy of the scattered lepton
2	theta_l	θ_ℓ, radian	Polar angle of the scattered lepton
3	phi_l	φ_ℓ, radian	Azimuthal angle of the scattered lepton
4	E_p	E_p, MeV	Full energy of the recoil proton
5	theta_p	θ_p, radian	Polar angle of the recoil proton
6	phi_p	φ_p, radian	Azimuthal angle of the recoil proton
7	E_g	E_γ, MeV	Energy of the bremsstrahlung photon
8	theta_g	θ_γ, radian	Polar angle of the bremsstrahlung photon
9	phi_g	φ_γ, radian	Azimuthal angle of the bremsstrahlung photon

Table 1. The branches contained in the `ntp` tree.

always contains the kinematic parameters of three particles ($\ell^\pm$, p, and γ). In the case of elastic events, the kinematic parameters E_γ, θ_γ, and φ_γ are set equal to zero. Events of both types are uniformly mixed with each other in the output files.

References

[1] https://github.com/gramolin/esepp/

[2] *A. V. Gramolin, V. S. Fadin, A. L. Feldman, et al.* A new event generator for the elastic scattering of charged leptons on protons. arXiv:1401.2959.