Single Arm Monte Carlo for polarized ^{3}He experiments in Hall A. V.0.2

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August 30, 2000

Abstract

This manual describes the Monte Carlo written for the experiment E94010 in Jefferson Lab Hall A. The codes allow to simulate the two High Resolution Spectrometers of Hall A. It is setup for a ^{3}He polarized target single arm (e,e') experiment but can easily be adapted for any single arm (e,e') experiments. ^{3}He asymmetries, cross sections and radiative process are included.

Contents

1 Introduction

This note is a manual for mce94010, a single arm Monte Carlo simulating a Hall A HRS (High Resolution Spectrometer). mce94010 simulates the Hall A electron HRS spectrometer acceptance. A version named mce94010h is available and simulates the Hadron arm. In addition physics models were added (so far only He3 elastic and quasi-elastic, with possibility of radiative corrections). All the sources can be found in the directory: /work/halla/e94010/disk2/deurpam/espace/mc/mc_unif

2 MCE94010 Features.

mce94010 works the following way. The kinematic domain illuminated and the region of interest for the analysis are defined in the input files. Then the relevant variables are randomly drawn (uniform distribution). All these variables define an event. The event undergoes different checks to see if it reaches the HRS focal plan without being stopped by the various apertures within the spectrometer. If so the event is reconstructed at the target and stored in the output file. Meanwhile, multiple scattering, each time the electron is crossing some matter, and radiative energy losses are applied. Before to store the event, a weight corresponding to the cross section of the event and an asymmetry can be assigned. This option is set on or off using the input file. The characteristics of mce94010 are the following:

- It contains the Hall A HRS geometry. For each arm four versions of the Monte Carlo exist. The first one uses the standard Hall A transport functions from J.J. LeRose. The second uses the acceptance function developed for the VCS (Virtual Compton Scattering experiment E93050) from H. Fonvieille and S. Jaminion (cf paragraph 7). The third one uses the forward transport functions of J. LeRose and the optic database to reconstruct. The last version uses X. Jiang acceptance.
- The reference frame used inside the spectrometer is the usual spectrometer transport coordinates (defined in the ESPACE manual). The frame used for target quantities is the Hall A reference frame.
- It needs a link to the cernlib because of the random generation function.

- Incoming and scattered electron energy losses (ionization, external and internal bremsstrahlung) are taken into account according to the setup of the E94010 experiment.
- A raster (circular or squared raster pattern) option can be set.
- The program runs with the 6 mSr collimator as the experiments usually run. However if one wants to have the collimator out, one has to comment the test inside the code and to recompile it.
- ^{3}He Elastic, quasi-elastic or phase-space can be chosen.

3 Input files.

In order to run, the Monte Carlo needs two input files. The first one named "mce94010.inp " (electron arm) or "mce94010h.inp" (hadron arm) contains the physics parameters and the kinematic domain one wishes to illuminate (from now we will refer to the cuts used to define this region as "illumination cuts". The contain of the file is detailed below:

3.1 Physics input file

- n_trial: Number of events used to illuminate the kinematic domain.
- Ei: Beam energy (in GeV) .
- Ep: Spectrometer central momentum setting (in GeV/c) .
- th_spec: Spectrometer angle (in degree).
- dpp_ac: Relative momentum range (in %) where the $\Delta p/p$ value of the drawn event has to be chosen. It has to be greater than the HRS $\Delta p/p$ acceptance in order to provide a complete illumination. One has to put the full range value (i.e. not +/- x but 2x).
- dth_ac: θ range (vertical angle) where the θ value has to be drawn (in mR). It has to be chosen larger than the HRS vertical angular acceptance.
- dph_ac: φ range (horizontal angle) where the φ value has to be drawn (in mR). It has to be chosen larger than the HRS horizontal angular acceptance.
- spot_x: Total rastering size in the horizontal direction (in meter). It's either the length of the rectangular rastering pattern (square raster) or the diameter of the elliptic rastering pattern (elliptical raster). To turn off the raster, put a small value for this variable and the next one.
- spot_y: Total rastering size in the vertical direction (in meter). It's either the length of the rectangular rastering pattern (square raster) or the diameter of the elliptic rastering pattern (elliptical raster) .

- tgt_l: Target length in the z direction (cm).
- aspin: Orientation of the target polarization in the Hall A frame. (in degree) .
- choice: Set to 1, it enables the cross section and asymmetry computation in the elastic case. Set to 2, it enables the quasi-elastic physics. If one is interested only by phase space, one has to set this variable to 0.
- inl: Thickness of the matter crossed by the incoming electron (in radiation length). It is used to compute the energy losses due to internal and external bremsstrahlung for the incoming particles.
- outl: Thickness of the matter crossed by the scattered electron (in radiation length). It is used to compute the energy losses due to internal and external bremsstrahlung for the scattered particles.
- xdi: Average density multiplied by the thickness of the matter crossed by the incoming electron (in g.cm^{-2}). It is used to compute the energy losses due to ionization for the incoming particles.
- xdo: Average density multiplied by the thickness of the matter crossed by the scattered electron (in g.cm^{-2}). It is used to compute the energy losses due to ionization for the scattered particles.
- rc: Enable the radiative corrections if rc=1. If rc=0, the radiative corrections are not taken into account.

3.2 acceptance input file

If the elastic option is enabled the cross section is displayed after each run of the Monte Carlo. In order to compute it one has to know the experimental cuts applied in the experimental data analysis. The acceptance input file contains these informations. The file name is "cute.inp" for mce94010 and "cuth.inp" for mce94010h.

Note: The contain of this file has no effect on the spectra computed by the Monte Carlo but only on the cross section given at the end of a run. The file structure is as following (units are the same than for the previous input file):

- dpp_max: cut applied on the high $\Delta p/p$ value in the analysis of the experimental data
- dpp_min: cut applied on the low $\Delta p/p$ value in the analysis of the experimental data
- dth_max: cut applied on the high θ value (vertical angle) in the analysis of the experimental data
- dth_min: cut applied on the low θ value in the analysis of the experimental data

- dph_max: cut applied on the hight φ value (horizontal angle) in the analysis of the experimental data
- dph_min: cut applied on the low φ value in the analysis of the experimental data
- tgt_max: higher value of the cut applied on the target length (in the z direction)
- tgt_min: lower value of the cut applied on the target length (in the z direction)
- w_min: lower value of the cut applied on w-m where m is the ^{3}He mass (in GeV)
- w_max: Higher value of the cut applied on w (in GeV)

In order to have a complete illumination and therefore a meaningful cross section, all these cuts have to be smaller than the illumination cuts chosen in the physics input file. An error message will warn if the physics cuts are larger than the illumination cuts.

4 Output Files.

4.1 *PAW* ntuple output file

The output file name is "mcentp.hbook" for mce94010.f and "mchntp.hbook" for mce94010h.f. It is an hbook file containing a large size "row wise ntuple" for *PAW*[1]. The list below describes its content. All the events stored in the ntuple have successfully met the HRS focal plan.

- Zlab: Vertex position along the incoming beam direction (cm).
- deltat: Reconstructed $\Delta p/p$ (in %) at the target.
- thetat: Reconstructed θ at the target (mR). In the spectrometer frame.
- phit: Reconstructed φ at the target (mR). In the spectrometer frame.
- yt: y in the spectrometer frame (in cm).
- xs: Weight for the cross section.
- asy. Asymmetry computed with the event target reconstructed quantities.
- wmm. w-m where m is the ^{3}He mass (in GeV).
- dEtot. Total energy loss due to radiative processes.

[1] if one does not like to use paw, one just has to uncomment the part of the code above the one filling the ntuple. It will write the Monte Carlo output as an usual file.

The following quantities are not stored in the ntuple but can be easily implemented (one has however to modify the source code):

- x_focal: Horizontal coordinate in the focal plane (in cm).
- y_focal: Vertical coordinate in the focal plane (in cm).
- theta_focal: Vertical angle in the focal plane (in mRadian).
- phi_focal: Horizontal angle in the focal plane (in mRadian).
- delta_P: Fraction of the momentum relative to the central HRS momentum setting (in %) in the focal plane.
- X_raster: Horizontal position on target (cm) in the Hall frame.
- Y_raster: Vertical position on target (cm) in the Hall frame.
- delta_P_origin: Drawn $\Delta p/p$ during the event generation (in %).
- y_origin: Drawn y during the event generation. In the spectrometer frame (in cm).
- theta_origin: Drawn θ during the event generation in the spectrometer frame (in mR).
- phi_origin: Drawn φ during the event generation in the spectrometer frame (in mR).
- accept (mce94010xj and mce94xjh versions only). Acceptance weight of the event.

5 Compilation.

mce94010 compiles on HP using the makefile creer (command: creer mce94010 or creer mce94010h).

6 Acceptance Function.

Four versions of mce94010 exist:

6.1 mce94010 and mce94010h.

The first one uses J.J. Lerose transport functions. It allows to compute focal and target quantities. A function transports the electron from the target to each of the magnet apertures or collimators affecting the acceptance. All these functions are fits of the results given by SNAKE [1], a ray tracing program using the magnet field maps to compute the particle trajectories. They allow to test if the electron passes all the apertures and see the different effects of these apertures. The quantities at the target are reconstructed using the inverse functions. The name of this Monte Carlo version is mce94010.f for the electron arm and mce94010h.f for the hadron arm.

6.2 mce94010lpc.

The second version uses the VCS acceptance function from H. Fonvieille and S. Jaminion. No physics nor radiative corrections are implemented in this version of the Monte Carlo. Only white spectra (i.e. phase space) are available. This version is named mce94010lpc.f. The function used here is a polynomial fit of the acceptance tested with SNAKE. It is a logical function returning a positive answer if the event is in the acceptance. Consequently this version of the Monte Carlo provides only unreconstructed target quantities. It was coded as a check of the first Monte Carlo version and the two results agree well for all the target quantities, except for $\Delta p/p$. The J.J Lerose functions agree with deep inelastic experimental data taken during the experiment E94010 while the VCS acceptance function does not, as far as the data of e94010 are concerned.

6.3 mce94010r

This version use J.J Lerose functions to provide the focal quantities and the experimental optic database optimised using the E94010 ^{12}C data to reconstruct the target quantities [8]. This version need a third input file named dbe.inp containing the optic database. This version is slower than the two previous ones.

Note: y target is wrongly reconstructed by this version. Also the phi target spectrum is too wide. See [9].

6.4 mce94010xj and mce94010xjh

The last versions use X. Jiang acceptance function. The acceptance data are contained in the files xjinp.hbook and xjinph.hbook. These files are generated by X. Ji simulation [7]. This simulation needs the same illumination than the one chosen in the mce94010.inp file. The acceptance is binned in (dp/p, θ_t, φ_t, y_t). The maximum bin is 40 for each variable. Given the statistic available in the xjinp.hbook and xjinph.hbook files, the optimal binning is $(8\times14\times20\times20)$. In one want to change this setting, one has to modify these parameters in the source code. The acceptance in a bin is defined as the number of events in the selected bin normalized to the number of events in the central bin. **Then the event has to be weighted by the acceptance**. This is a particular feature of this version. In the other versions the events either pass the acceptance or are removed. Here all the event are kept and the acceptance effect is obtained by a weight. Note that if one wants to save disk space one can remove the event having 0 as a weight. This is not done in the present mce94010xj and mce94010xjh versions.

The binning used is rather crude due to the statistical limitation of the xjinp.hbook and xjinph.hbook files. For improvement, the results are smoothed by a four-dimensional interpolation.

6.5 Comparison

A comparison of the different Monte Carlo version and the experimental data was done [9] for a 1cm target, a 15 cm target and a 40 cm target. The following conclusions are not including mce94010r since it gives unsatisfactory results.

To summarize:

- **1cm and 15 cm targets**: All the versions and data agree well for 1 cm and 15 cm targets. However the phi_target is overestimated for values larger than 10 mR for both mce94010 and mce94010lpc.

- **40 cm target**: mce94010lpc is not reproducing the relative momentum dp/p for the 40 cm target. mce94010 and mce94010lpc are still overestimating phi_target for values larger than 10 mR. As a consequence y_target data are not fitted well for there negative values. mce94010xj is matching well the data.

7 Physics in mce94010

Physics can be added into the Monte Carlo results as a weighting factor (cross section effect) or an asymmetry. They are both computed for each event according to its target reconstructed kinematic quantities.

7.1 Elastic cross sections and asymmetries.

^{3}He elastic cross section and asymmetries are available. They relies on a world data fit of the ^{3}He elastic form factors [2].

The way the code treats the elastic is different from the other physics choices because of the correlation between the scattering angle and the outgoing electron momentum. In this case, only the scattering angle is chosen randomly. Then the momentum of the scattering particle is computed according the random value of the angle, the mass of the target (^{3}He) and the incoming energy.

To enable the elastic in the Monte Carlo, the variable "choice" in the input file has to be set to 1 (see paragrapher 3.1)

7.2 Quasi-elastic cross sections and asymmetries.

The ^{3}He quasi-elastic computation is based on a PWIA model [3]. Unlike the elastic where the asymmetry and the cross section can be quickly computed, the PWIA model is a rather slow code. To avoid to run it for each event, different files of data covering the kinematic domain of the experiment E94010 are stored in the directory /qel.dir. Each file corresponds to a particular energy from 0.700

GeV to 5.07 GeV. A file is available each 0.1 GeV roughly. After one has set the incoming beam energy in the physics input file, the Monte Carlo picks up the closest energy available in these files. The file contains a set of energy losses covering the quasi-elastic region. The Monte Carlo will interpolate between the energy loss values to get the asymmetry and cross section at the energy loss drawn.

Only the kinematic range of experiment e94010 is available so far. Only ionization and external bremsstrahlung is available.

8 Radiative corrections.

Radiative corrections can be turn on by setting the variable "rc" to 1 in the physics input file. To turn them off, set it to 0. Vacuum polarization, vertex corrections, ionization, external and internal bremsstrahlung are treated.

8.1 Losses by bremsstrahlung

8.1.1 External bremsstrahlung

The probability of energy loss by external bremsstrahlung is given by:

$$I_{ext}(E_0, E, t) = \frac{bt}{\Gamma(1+bt)}(\frac{\Delta E}{E_0})^{bt}\frac{\psi(\frac{E_0-E}{E})}{E_{0-E}}$$

(this Tsai's result and comes from [4]) where:

- I_{ext} is the probability distribution for an electron of energy E_0 to lose an energy $\Delta E = E_0 - E$ after passing through a length t of matter.
- t is the length of matter in radiation length.
- $\Gamma \simeq$1-0.772bt
- $b = \frac{4}{3}[1 + \frac{(Z+1)}{9ln(1194Z^{-2/3}+ln(184.15Z^{-1/3})}]$ where Z is the averaged charge of the nuclei composing the matter crossed by the electron.
- $\psi(y) = 1 - y + \frac{3}{4}y^2$ is the screening factor.

8.1.2 Internal Bremsstrahlung

The energy loss probability distribution by internal bremsstrahlung is given by:

$$I_{int}(E_0, E_0 - k_0, \nu) = \frac{\nu}{k_0}(\frac{k_0}{E_0})^{\nu}\psi(\frac{k_0}{E_0})$$

where:

- $\nu = \frac{2\alpha}{\pi}(ln\frac{-q^2}{m^2} - 1)$ with α the fine structure constant, q the transfered quadri-momentum and m the electron mass.
- k_o is the energy lost by internal radiation.

8.1.3 Distribution probability.

The two probability distributions have a similar shape very peaked at zero energy loss (infinite probability of losing energyless photons). For Monte Carlo purpose, an efficient way to generate a random energy loss ΔE according to these probability is given in [5]:

$$\Delta E = E_0 R^{1/bt}$$

where R is a random number with an uniform distribution (between 0 and 0.99 to not allow the electron to lose all its energy).

8.2 Ionization

The probability distribution of energy loss Δ by ionization is a Landau distribution. For ultrarelativist electrons this distribution is very peaked at Δ_0, the most probable energy loss by ionization. It is given by [4] [6]:

$$\Delta_0 = \xi(ln\frac{\xi}{\epsilon'} + 0.37)$$

where:

- $\xi = \frac{2\pi\alpha^2 N_a}{m\beta^2}\frac{Z}{A}d$ with N_a the Avogadro number, $\beta = \frac{v}{c}$, A the averaged mass number of the matter crossed by the electron and d the averaged density multiplied by the length of the crossed matter.
- $ln\epsilon' = ln\frac{(1-\beta^2)I_0^2 Z^2}{2m\beta^2} + \beta^2$ with $I_0 = 13.5\times10^{-3} MeV$, the ionization energy of the hydrogen atom.

The Landau distribution $\Phi(\lambda)$ is an universal function of the variable λ with :

- $\lambda = \frac{\Delta - \Delta_0}{\xi}$
- $\Phi(\lambda) = \frac{1}{\pi}\int_0^\infty e^{-uln(u)-u\lambda} sin(\pi u) du$

$\int_o^x \Phi(\lambda) d\lambda$ is used to generate a random energy loss Δ following the $\Phi(\lambda)$ distribution for the incoming and the scattered electron.

8.3 Vertex Correction and Vacuum Polarization.

The vertex and vacuum polarisation corrections are done using the standard formulae from [10]. The global formula taking into account the two effects is [11]:

$$\delta_{vac} + \delta_{vertex} = \frac{2\alpha}{\pi}(\frac{13}{12}ln(Q^2/m_e^2) - \frac{14}{9})$$

with δ defined as $\sigma_{exp} = \sigma_{Born}(1+\delta)$.

8.4 incoming particles

The energy of the incoming electrons is spread due the beam energy dispersion. Then the external bremsstrahlung, ionization and internal bremsstrahlung are applied. For the internal energy losses, one takes $\nu/2$, the other half of ν being for the outgoing electrons. The beam energy dispersion is taken as 3×10^{-5}.

8.5 outgoing particles

The energy of the outgoing electron just after the scattering is already spread by the beam energy distribution and the energy losses before scattering. The internal bremsstrahlung, external bremsstrahlung and ionization are applied. Spectrometer resolution smears the resulting energy[2][3]. Then the electron undergoes multiple scattering at each crossing of matter.

References

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[2] To fit the elastic data the hadron spectrometer resolution was taken at 3.10^{-4} and the electron spectrometer at 2.10^{-4}. The hadron spectrometer resolution is wider because of the hysteresis problem occurring during the e94010 data taking.

[3] In the particular case of the mce94010lpc and mce94010xj versions the VDC resolution is not taken into account (no transport matrix is available to go in the focal plan). Hence the HRS resolution has to be increased to 5.10^{-4} ("hadron arm") and 4.10^{-4} ("electron arm").

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