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EVENT GENERATOR OF ELECTRON-NUCLEUS REACTIONS

(EN_GEN ver. 1.01)

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Abstract :

Models for electroproduction on nuclei are used for event generation in real geometry. The quasielastic and inelastic channels are generated separately, which allow to estimate the relative contributions in the given range of Q^2 and W^2. The Cross sections are calculated in the Light Cone Impulse approximation, where the high momentum component of the nuclear spectral function is described in the framework of nucleon - nucleon correlations. The Final State interaction of outgoing nucleons are considered according to the Glauber approximation implemented by Color Transparency Phenomena. Output of the "EN_GEN " generator is the multi parameter (42) NTUPLE file, which consists to multihadron final states. This file can be used as input for any program simulating the designed experimental arrangement for the purpose of studying electroproductions on the nuclei. The calling of NTUPLES in PAW allows one to do the many parameter kinematical analysis of reactions considered.

1.Introduction

The multihadron mesurements are one of the important parts in the Physics Program approved for CEBAF. The many particles in the final state make the kinematical and dinamical analysis of this processes more complicated. This work aimed to introduce the event generator "**EN_GEN**", where the realistic models are used for simulation of the events as a product of electroproduction on nuclei.

The range of generation is defined by the user via an input file, where the low and upper values of Q^2, W^2, and three momenta of interacting nucleon are specified.

The generated events output in **NTUPLE** format more completely use the possibility of many - parameter analysis of the program package PAW [1]. Apart from this, the output files can be used as inputs to programs developing the software for experimental arrangements designed for the electroproduction physics on nuclei.

2.Physics Included into the Generator

The following processes are included in event generation:

2.1 Inclusive $(e, e\prime)$ scattering

In this case, generation is performed in the full region of momenta and angles of initial nucleon. The user will be interested only in three momenta of scattered electron and parameters coming from incident and scattered electron momenta (such as Q^2, q_0, W^2, $X = \frac{Q^2}{2mq_0}$). The cross sections are calculated on the basis of Light Cone Impulse approxomation [2]. For the quasielastic reaction the dipole parametrization of nucleon form factor have been used and for the inelastic one, only Δ - isobar production is considered. For this case the parametrization of inelastic form factors from [3] have been used.

The spectral function is constructed by the simple Fermi step distribution at the quasifree (under Fermi surface) region and the distribution coming from predictions of two nucleon short-range correlation in the region forbidden for scattering on free nucleon with momentum $\leq p_{Ferm}$.

2.2 The $(e, e\prime, N_f(\pi_f))$ scattering

The exclusive $(e, e\prime, N_f(\pi_f))$ cross section has been calculated using the above mentioned model. Here a nucleon is knocked out by virtual photon (quasielastic scattering) or this nucleon (as well as π meson) is a product of produced Δ decay. The final state interaction is included by the standard Glauber[4] approximation, which in the special case can be modified by Color Transparency Phenomena[5] (the perturbative QCD prediction[6] have been used in the calculation).

2.3 The $(e, e\prime, N_s)$ scattering

Since the two nucleon short-range correlation assumed relevance for the high momentum component of nuclear wave function, the enhancement of fast ($> p_{Ferm}$) spectators is predicted if these type of correlations disturbed by virtual photon. The momentum of the initial nucleon belongs to this correlation defined by the relations, $\vec{p}_i = -\vec{p}_s$, since the center of mass of correlation is assumed at rest.

The program also generates the number of evaporated spectators under the Fermi momentum surface, which are uncorrelated with the target nucleon.

2.4 The $(e, e\prime, N_f(\pi_f), N_s)$ scattering

This type of events are a direct consequence of the 2.2 and 2.3 mechanism. If $p_s \leq p_{Ferm}$ there are no correlation between $N_f(\pi_f)$ and spectators, another case correlation coming from the fact the forward nucleons(pions) are produced at the initial nucleon belonging to the correlation.

2.5 The $(e, e\prime, N_f, N_s, \pi_f)$ scattering

This reaction takes place if all hadrons are produced by a virtual photon, considered in coincidence with spectators. Such type of events allow an estimate of the absolute role of inelastic scattering.

2.6 The $(e, e\prime, N_f, N_s, N_r)$ scattering

This processes correspond to the case of rescattering of produced nucleon (or Δ - isobar) with Fermi nucleons. N_r corresponds to the rescattered nucleon at NN $\rightarrow$ NN reaction if quasielastic scattering takes place or NΔ $\rightarrow$ NN reaction for inelastic (Δ production) scattering occurs.

In this case the influence of Color transparency phenomena can be considered (see below).

3.INPUT for EN_GEN

Example of an input file **"EN_INIT.DAT"** is presented on fig.1, which in generaly used the principles of **"CELEG"** generator[7] inputs.

The meaning of each line in fig.1 is as follows:

BEAM ELECTRON 0.000 0.000 4.000 0.000 0.000 0.000

This line defines the electron primary momentum (energy).

I,II - unused

III - primary electon momentun

IV,V,VI - unused

SPECTATOR PROTON 0.000 0.700 0.000 180.000 0.000 360.000

This line defines the initial conditions for spectator.

PROTON - this is a type of spectator. It can also be **NEUTRON** or **UNKNOWN**, when neutron or (neutron/proton) type of spectators are generated.

I,II - are the low and upper values for spectator momenta between which the cross sections array is prepared for Monte Carlo event generation (in GeV/c);

III,IV - are the low and upper value of spectator polar angle with respect to the vector of virtual photon $\vec{q}$, (in deg.);

V,VI - are the low and upper value of spectator azimuthal angle, in the coordinate system, where $\vec{q} \parallel \hat{z}$, (in deg.). Note that for this the case user can define the low azimuthal limit as negative (e.g. "V"=-10, "VI"=10) too.

Above defined ranges is used as a range for calculation of the cross section's array. The interacting nucleon parameters are defined as $\vec{p_i} = -\vec{p_s}$ and $E_i = E_s$ at $p_s < p_{Fermi}$ or $E_i = M_D - E_s$ at $p_s > p_{Fermi}$. Therefore the cross sections for following Monte Carlo generation are defined in the coordinate system, where $\vec{q} \parallel \hat{z}$. Note that in the output the momenta of spectator with the underfermi momenta are regenerated as evaporated nucleons.

KNOCK_OUT PROTON 0.000 99.900 0.000 180.000 0.000 360.000

This line defines the cuts of calculated cross sections by knock out nucleon momentum (at the quasielastic scattering) , in the system where $\vec{q} \parallel \hat{z}$.

PROTON - this is a type of Knock out nucleon (or decayed nucleon at the Δ production). It can also be **NEUTRON** or **UNKNOWN**, when neutron or (neoutron/proton) type of knock outs are generated.

I,II - range of momentum;

III,IV - range of polar angle with respect to $\vec{q}$;

V,VI - range of azimuthal angle, in the system where $\vec{q} \parallel \hat{z}$.

NUCLEUS 12.000 6.000 0.220 0.000 0.000 0.000

This line defines the type of target nucleus:

I - atomic number;

II - number of protons;

III - value of Fermi momentum in GeV/c;

IV,V,VI - unused.

Q2 RANGE 1.000 6.000 0.000 0.000 0.000 0.000

This line defines the range of Q^2 (in $(GeV/c)^2$) where the cross sections are calculated for Monte Carlo generation :

I - low limit;

II - upper limit;

III,IV,V,VI - unused.

W2 RANGE -1.200 1.100 0.000 0.000 0.000 0.000

This line defines the range of the square of final hadron mass produced on hydrogen target ($W^2 = M^2 + 2Mq_0 - Q^2, in (GeV/c)^2$), where the cross sections are calculated.

I - low limit;

II - upper limit;

III,IV,V,VI - unused.

X CUTS 0.010 1.980 0.000 0.000 0.000 0.000

This line defines the $X = \frac{Q^2}{2Mq_0}$ cuts for generated events ($0 < X > 2$);

I - low limit;

II - upper limit;

III,IV,V,VI - unused.

Pe' CUTS 0.010 99.000 8.000 45.000 0.000 360.000

This line defines the cuts of scattered electron momentum and angles in the real geometry, where $\hat{z}$ is parallel to direction of primary electron beam.

I,II - range of momentum (in GeV/c);

III,IV - range of polar angle (in deg.);

V,VI - range of azimuthal angle (in deg.) (V - can also be negative).

Pf CUTS 0.010 99.000 4.000 180.000 0.000 360.000

This line defines the cuts of forward nucleon momentum and angles in the real geometry, where $\hat{z}$ is parallel to the direction of the primary electron beam. Hereafter, this is the nucleon which is knocked out at quasielastic scattering and is the produced nucleon at Δ production.

I,II - range of momentum (in GeV/c);

III,IV - range of polar angle (in deg.);

V,VI - range of azimuthal angle (in deg.) (V - can also be negative).

Ps CUTS 0.010 99.000 4.000 180.000 0.000 360.000

This line defines the cuts of spectator nucleon momentum and angles in the real geometry, where $\hat{z}$ is parallel to the direction of the primary electron beam.

I,II - range of momentum (in GeV/c);

III,IV - range of polar angle (in deg.);

V,VI - range of azimuthal angle (in deg.) (V - can be also negative).

AL CUTS 0.010 1.980 0.000 0.000 0.000 0.000

This line defines the cuts on Light Cone parameter α, which defines the fraction of pair correlation momentum carried by spectators ($0 < \alpha < 2$).

I - low limit;

II - upper limit;

III,IV,V,VI - unused.

EVENTS 50000.000 0.000 0.000 0.000 0.000 0.000

I - number of generated events;

II - VI - unused.

QUASIELAS YES

This line defines whether the quasielastic scattering is taken into account.

DELTA1232 YES

This line defines whether Δ production is taken into account.

FSI **YES**

This line defines whether the final state interaction is taken into account.

CT **NOT**

This line defines whether the color transparency is taken into account.

NTUPLE **YES**

This line defines whether NTUPLE file is output from **EN_GEN**. If this is the case, the NTUPLE file is defined as follows:

NTUPLE NAME (max-20chr) >en_gen at 4 Gev

This line defines the title of the ntuple file which is called from PAW[1] (for example by "NTUPLE/PRINT ID"). Note that the title name cannot be longer than 20 characters.

RZDAT NAME (max-20chr) >SCR:HE4_NCT4.RZDAT

This line defines the name of RZDAT file in which the NTUPLE events are writed. In this particular case the *HE4_NCT4.RZDAT* file will be created in the SCR directory.

NTUPLE ID **>5**

This line defines the NTUPLE identifier by which it is called from PAW.

LRECL (4096 for large) **>4096**

This line defines the record size for events to be written into the NTUPLE file.

NPRIME (60000 for large) **>60000**

This line defines the size of primary allocation (see [1]).

EXTRA LARGE **>0**

This line specifies the extra large situation with 1. The 0 value is the normal and large situation. For more detail see [1].

4.OUTPUT from EN_GEN

ASCII outout:

The ASCII output "**EVENT_OUT.DAT**" available for **EN_GEN** is practically the same as for **CELEG** [7]. In this output file (fig.2) the input dates are represented, then the calculated total cross section is presented under the kinematical limit defined in the input file. The last part of **EVENT_OUT.DAT** demonstrate the data structure for the first 20 generated events. The line titled "SUM" represents the sum of charge, momentum components, energy and mass of particles included in this event. Note that this "SUM" represents the energy and momentum conservation only for the events where there are no FSI and where the momentum of spectator exceeds to Fermi momentum. Momenta of evaporated spectators ($< p_{Ferm}$) and the momenta of fermi nucleons on which the produced hadrons are rescattered, are regenerated independently of main proceses.

NTUPLE output:

Each event included into NTUPLE, is characterized by the following (41) parameters:

Ee - energy of incident electron;

Q2, W2, X - four momentum square transferred, final hadron mass square produced on hydrogen and Bjorken variable defined for hydrogen;

W2n, Xn - final hadron mass square and Bjorken X on off shell nucleon target;

q0, qv, THeq - energy, momentum and polar angle with respect of electron beam of virtual photon;

Ees, pes, THe_e, PHIe_e - energy, momentum, polar and azimuthal angles of scattered electron. All angles are defined in the system where $\hat{z}$ is parallel to beam direction;

Ei, pi, THi_e, PHIi_e, ALF_i - energy, momentum, polar, azimuthal angle and light cone parameter for initial off shell nucleon. All angles are defined in the system where $\hat{z}$ is parallel to beam direction;

THi_q, PHIi_q - polar and azimuthal angles of initial off shell nucleon. The angles are defined in the system where $\vec{q} \parallel \hat{z}$;

Ef, pf, THf_e, PHIf_e, ALF_f - energy, momentum, polar, azimuthal angles and light cone parameter for forward nucleon. All angles are defined in the system where $\hat{z}$ is parallel to beam direction.

Forward means: knock out at no FSI quasielastic scattering case, knock_out and elastically rescattered at FSI one rescattered case, produced after no FSI Δ decay case and produced after Δ production and $\Delta N \rightarrow$ NN FSI case;

THf_q, PHIf_q - polar and azimuthal angle of forward nucleon. The angles defined in the system where $\vec{q} \parallel \hat{z}$;

ES, pS, THS_e, PHIS_e, ALF_S - energy, momentum, polar, azimuthal angles and light cone parameters for spectator nucleon. All angles are defined in the system where $\hat{z}$ is parallel to the beam direction;

THS_q, PHIS_q - polar and azimuthal angles of spectator nucleon. The angles are defined in the system where $\vec{q} \parallel \hat{z}$;

N_SCATf - the number of FSI: 0 - no FSI; 1 - one NN $\rightarrow$ NN elastic rescattering at quasielastic case and $\Delta N \rightarrow$ NN at Δ production case; 2 - two rescattering; 3 - three rescattering; 4 - four rescattering; 5 - inelastic FSI. For the case of 2,3,4,5 no additional processes are considered. Note that the probability to find different values of **N_SCATf** depends on the Nucleus, forward nucleon momenta and whether Color Transparency phenomena is taken into account;

PROCESS - type of reaction, 1.0 - quasielastic, 2.0 - Δ production;

Er, pr, THr_e, PHIr_e, THR_q - energy, momentum, polar, azimuthal angles, when $\hat{z} \parallel$ beam, and polar angles with respect of $\vec{q}$ of rescattered particle. Rescattered particle is - nucleon from NN $\rightarrow$ NN, when **N_SCATf**=1 and **PROCESS** =1.0; - nucleon from $\Delta N \rightarrow$ NN, when **N_SCATf**=1 and **PROCESS** =2.0 and - π meson, when **N_SCATf**=0 and **PROCESS** =2.0. For the remaining case no rescattered particles are considered;

TYPE_f, TYPE_S, TYPE_r - type of forward, spectator and rescattered particles; -17 - π^-; 23 - π^0; 17 - π^+; 41 - proton; 42 - neutron.

5.EN_GEN by Example

User can find the executable of **EN_GEN** on the unprotected directory **USER14:[SARGSYAN.EN_GEN]** on VAX-VMS MICRO3.
So, for runing the **EN_GEN** the following type of COM files are suggested on the user's directory:

EN_GEN.COM:

```
$ DEFINE SCR SCRATCH2:[SARGSYAN]
$ ASSIGN USER_DIRECTORY:EN_INIT.DAT FOR015
$ ASSIGN USER_DIRECTORY:EVENT_OUT.DAT FOR011
$ RUN/NODEB USER14:[SARGSYAN.EN_GEN]EN_GEN.EXE
$ EXIT
```

$ DEFINE SCR SCRATCH2:[SARGSYAN] - this line defines the scratch directory on which the ntuple will be created. The user can define the SCR as the permanent directory too (if there is enough space quota).

$ ASSIGN USER_DIRECTORY:EN_INIT.DAT FOR015 - this line assigns the input files described in sec.3.

$ ASSIGN USER_DIRECTORY:EVENT_OUT.DAT FOR011 - this line assigns the output ASCII file described on sec.4.

$ RUN/NODEB USER14:[SARGSYAN.EN_GEN]EN_GEN.EXE - this line runs the program code from USER14:[SARGSYAN.EN_GEN] directory.

When the program is completed, the user can find the **HE4_NCT4.RZDAT** file on the **SCR** directory, which can be called from PAW. For details on the operation with NTUPLE files see [1].

6.Problems Occured

The program code uses the manydimensional arrays needing large memory space. If the user finds problems coming from insufficient virtual memory, he must contact the system's person to provide the proper space.

To contact the system's person need too if by some reason the directory of **USER14:[SARGSYAN.EN_GEN]** unreachable.

Another problems come from the power of computer. For example on the the MICRO3 (40mips) the 50000 events (with calculation of cross section's array) generated $\approx$ 1 hour.

Since the arrays which generate the random events have restricted dimensions for high accuracy achievement a restricted range for calculation of cross sections (and events generation) is suggested.

The errors will be found if the input data positions distroyed in the **EN_INIT.DAT** file. For restoring this file user can use the examples from **USER14:[SARGSYAN.EN_GEN]**.

So far as no long executive experience of **EN_GEN**, the author will be grateful for any comments, moreover for point out any errors to
SARGSYAN@CEBAF.GOV

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Reference

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```
BEAM         ELECTRON          0.000     0.000     4.000     0.000     0.000     0.000
SPECTATOR    PROTON            0.000     0.700     0.000   180.000     0.000   360.000
KNOCK_OUT    PROTON            0.000    99.900     0.000   180.000     0.000   360.000
NUCLEUS                        4.000     2.000     0.160     0.000     0.000     0.000
Q2    RANGE                    1.000     3.000     0.000     0.000     0.000     0.000
W2    RANGE                   -1.100     2.100     0.000     0.000     0.000     0.000
X     CUTS                     0.010     1.980     0.000     0.000     0.000     0.000
Pe'   CUTS                     0.010    99.000     8.000    45.000     0.000   360.000
Pf    CUTS                     0.010    99.000     4.000   180.000     0.000   360.000
Ps    CUTS                     0.010    99.000     4.000   180.000     0.000   360.000
AL    CUTS                     0.010     1.980     0.000     0.000     0.000     0.000
EVENTS                      5000.000     0.000     0.000     0.000     0.000     0.000

QUASIELAS    YES
DELTA1232    YES
FSI          YES
CT           NOT

NTUPLE       YES
_____________________________
NTUPLE NAME (max-20chr) >en_gen at 4 Gev
RZDAT  NAME (max-20chr) >SCR:HE4_NCT.RZDAT
NTUPLE ID               >5
LRECL  (8192 for large) >4096
NPRIME (60000 for large)>60000
EXTRA LARGE             >0
________________________>
```

Fig.1

```
BEAM        ELECTRON      0.000     0.000     4.000     0.000     0.000     0.000
SPECTATOR   PROTON        0.000     0.700     0.000   180.000     0.000   360.000
KNOCK_OUT   PROTON        0.000    99.900     0.000   180.000     0.000   360.000
NUCLEUS                   4.000     2.000     0.160     0.000     0.000     0.000
Q2     RANGE              1.000     3.000     0.000     0.000     0.000     0.000
W2     RANGE             -1.100     2.100     0.000     0.000     0.000     0.000
X      CUTS               0.010     1.980     0.000     0.000     0.000     0.000
Pe'    CUTS               0.010    99.000     8.000    45.000     0.000   360.000
Pf     CUTS               0.010    99.000     4.000   180.000     0.000   360.000
Ps     CUTS               0.010    99.000     4.000   180.000     0.000   360.000
AL     CUTS               0.010     1.980     0.000     0.000     0.000     0.000
EVENTS                 5000.000     0.000     0.000     0.000     0.000     0.000

QUASIELAS   YES           0.000     0.000     0.000     0.000     0.000     0.000
DELTA1232   YES           0.000     0.000     0.000     0.000     0.000     0.000
FSI         YES           0.000     0.000     0.000     0.000     0.000     0.000
CT          NOT           0.000     0.000     0.000     0.000     0.000     0.000

__________________________
NTUPLE NAME (max-20chr) >en_gen at 4 Gev
RZDAT  NAME (max-20chr) >SCR:HE4_NCT.RZDAT
NTUPLE ID               >     5
LRECL  (8192 for large) > 4096
NPRIME (60000 for large)>60000
EXTRA LARGE             >     0
________________________>

Total Cross Section  =    0.7868448257E+01  nano barn

    (Relativistic case)

                    LUND FORMAT DATA

                    LUND DATA LIST

SCATTERED     E -             0.919   0.000   3.201   3.330   0.001
SPECTATOR     P +            -0.043   0.073  -0.140   0.952   0.938
PRODUCED      P +            -0.876  -0.073   0.939   1.592   0.938
SUM             1.000         0.000   0.000   4.000   5.875   1.877

                    LUND DATA LIST

SCATTERED     E -            -0.814  -0.683   2.530   2.744   0.001
SPECTATOR     P +            -0.050  -0.018   0.081   0.943   0.938
PRODUCED      P +             0.843   1.068   1.303   2.105   0.938
PRODUCED      N 0             0.017  -0.282   0.227   1.006   0.940
SUM             1.000        -0.005   0.085   4.142   6.798   2.817

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                    LUND DATA LIST

SCATTERED     E -             0.972   0.000   3.172   3.318   0.001
SPECTATOR     P +             0.090  -0.058  -0.030   0.945   0.938
PRODUCED      P +            -0.974   0.072   0.900   1.626   0.938
SUM             1.000         0.088   0.014   4.041   5.889   1.877

TIME PER EVENT =         0.1169200018 SECONDS

TOTAL NUMBER OF EVENTS WRITTEN =               5000
```

Fig.2