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BMGA01, a Beam-gas Event Generator for ALEPH

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ABSTRACT

In this paper we describe the physics background and the usage of the BMGA01 beamgas event generator. The program simulates the main types of beam-gas events in an electron-positron collider. It has been interfaced to the GALEPH detector-simulation program.

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1. Introduction

BMGA01 is an event generator for beam-gas events as they will occur in the LEP collider. It has been written for the ALEPH experiment but could be used for the other LEP experiments as well. If the beam energy is sufficiently high (i.e. greater then 10 GeV) the routines can be applied to any other electron-positron experiment. The incoming electron is assumed to go in the positive-z direction, the incoming positron in negative-z direction. The generator is organized as a package of subroutines. The following processes are considered:

1. Møller scattering with the electrons of the beam-gas molecules.
2. Bhabha scattering with the electrons of the beam-gas molecules.
3. Elastic coherent Mott scattering of electrons/positrons by beam-gas nuclei (without considering the recoil of the nuclei which is rather small).
4. Elastic incoherent Rosenbluth scattering of electrons/positrons by protons/neutrons (considering the recoil).
5. Deep inelastic lepton nucleon scattering (here the program makes heavy use of the LEPTO program, see Ref. [1]).

There are two kinds of subroutines available: one kind computes the total cross section for the user selected process, the other kind does the Monte Carlo simulation. The user has to provide some flags and cuts (especially if the default values should be overwritten). An example is given below. All units are given in GeV, rad and nanobarn. The results are written into the LUND event record. An interface to the GALEPH program has also been implemented. The code is written in FORTRAN-77 and kept in a HISTORIAN library. However, source code is also available.
Initial results can be found in Ref. [2].

2. Physics and Monte Carlo method

In the beam pipe which is evacuated there will always be some residual gas molecules. Therefore one will have collisions between the accelerated particles (i.e. electrons and positrons) and those molecules. Different processes have to be investigated. First, there will be collisions with the shell electrons of the molecules. This can be a Bhabha-scattering or a Møller-scattering and produces δ-electrons. Collisions with the nucleons can be coherent (Mott scattering), incoherent (Rosenbluth scattering) or even deep inelastic. Bremsstrahlung (i.e. the Bethe-Heitler process) has not been included yet.

2.1. Møller Scattering

The differential cross section for Møller scattering can, for instance, be found in Ref. [3]. This formula for high energy electrons ($\beta = 1, \gamma \gg 1$) is approximately

$$\frac{d\sigma}{d\epsilon} = \frac{2\pi m_e r_0^2 Z}{E}\left[1 + \frac{1}{\epsilon^2} + \frac{1}{(1-\epsilon)^2}\right].$$

Here Z is the atomic number, r_0 the classical electron radius and ϵ is defined as

$$\epsilon = \frac{T}{E},$$

where T is the kinetic energy of the δ-electron.
The total cross section can be written as

$$\sigma = \frac{2\pi m_e r_0^2 Z}{E}\left[\epsilon_{max} - \frac{1}{\epsilon_{max}} + \frac{1}{1-\epsilon_{max}} - \epsilon_{min} + \frac{1}{\epsilon_{min}} - \frac{1}{1-\epsilon_{min}}\right].$$

To speed up the simulation an importance sampling technique is used. First we sample ϵ from $\frac{1}{\epsilon^2}$ and then sample it with the rejection method.

2.2. BHABHA SCATTERING

The differential cross section for high energies is approximately (neglecting the masses)

$$\frac{d\sigma}{d\epsilon} = \frac{2\pi m_e r_0^2 Z}{E}\left[3 + \frac{1}{\epsilon^2} - \frac{2}{\epsilon} - \epsilon + \epsilon^2\right],$$

where the notation is the same as in the previous section. The total cross section can be written as

$$\begin{aligned}\sigma =& \frac{2\pi m_e r_0^2 Z}{E} \times \\ & [-\frac{1}{\epsilon_{max}} - 2\ln\epsilon_{max} + 3\epsilon_{max} - \frac{1}{2}\epsilon_{max}^2 + \frac{1}{3}\epsilon_{max}^3 \\ & + \frac{1}{\epsilon_{min}} + 2\ln\epsilon_{min} - 3\epsilon_{min} + \frac{1}{2}\epsilon_{min}^2 - \frac{1}{3}\epsilon_{min}^3].\end{aligned}$$

The same sampling method as for Møller scattering is applied.

2.3. MOTT SCATTERING

A general formula for Mott scattering is given in Ref. [4]. If one neglects the recoil of the nucleon the formula simplifies to

$$\left(\frac{d\sigma}{d\theta}\right)_{Mott} = \frac{\alpha^2 z^2}{2E^2}\frac{(1+\cos\theta)}{(1-\cos\theta)^2}\sin\theta.$$

Here θ is the scattering angle of the electron/positron. Note that this formula is only valid for small scattering angles. Otherwise the nuclear recoil has to be taken into account (see next section).
Integrating this equation between θ_{min} and θ_{max}, one obtains the total cross section,

$$\begin{aligned}\sigma =& \frac{\pi\alpha^2 Z^2}{E^2} \\ & \times \left(-\frac{2}{1-\cos\theta_{max}} - ln(1-\cos\theta_{max}) + \frac{2}{1-\cos\theta_{min}} - ln(1-\cos\theta_{min})\right)\end{aligned}$$

For generating events we first sample θ from $\frac{1}{(1-\cos\theta)^2}$. Then we use the rejection method to accept/reject events.

2.4. ROSENBLUTH SCATTERING

Here we take into account the nuclear recoil and introduce form factors for the structures of protons and neutrons. The following formula is used (see Ref. [4]):

$$\frac{d\sigma}{d\theta} = \left(\frac{d\sigma}{d\theta}\right)_{Mott} \times \frac{1}{1+\frac{E}{M}(1-\cos\theta)} \times \left[\left(\frac{G_E^2 + \frac{q^2}{4M^2}g_M^2}{1+\frac{q^2}{4M^2}}\right) + \frac{q^2}{4M^2}2G_M^2\frac{1-cos\theta}{1+cos\theta}\right]$$

Here M is the mass of the nucleon and G_E^2 and G_M^2 are the electric and the magnetic form factors. The energy of the scattered lepton is given by

$$E' = \frac{E}{1+\frac{E}{M}(1-\cos\theta)}.$$

The squared four-momentum transfer is

$$q^2 = 2EE'(1-\cos\theta).$$

The form factors have been parametrized as described in Ref. [4]:

$$G_E^p(q^2) = G(q^2)$$

$$G_M^p(q^2) = |\mu_p|G(q^2)$$

$$G_M^n(q^2) = |\mu_n|G(q^2)$$

$$G_E^n(q^2) = 0$$

$$G(q^2) = \left(1+\frac{q^2}{M_V^2}\right)^{-2},$$

where μ_n and μ_p are the magnetic moments of the neutron and the proton, $M_V^2 = (0.84\ GeV)^2$ is a fitting parameter. The above relations hold at least up to $q^2 = 25\ GeV^2$.

The Monte Carlo method is again the rejection method as described in the previous section.

2.5. Deep inelastic lepton nucleon scattering

If particle masses are neglected the double differential cross section for deep inelastic lepton-nucleon scattering can be written as

$$\frac{d\sigma}{dxdy} = \frac{2\pi\alpha^2}{Q^4} s \left[1 + (1-y)^2\right] \sum_i e_i^2 x f_i(x, Q^2).$$

This formula (see Ref. [5]) has been implemented in the LEPTO program.
In the case of beam-gas events the invariant energy is given by

$$\sqrt{s} = 2\sqrt{ME},$$

where M is the mass of the nucleon and E the energy of the incoming lepton in the laboratory frame (lepton masses are again neglected).
The four-momentum transfer q is defined by

$$q = k - k'$$

where k is the four-momentum of the lepton before the collision and k' the four-momentum after the collision. By using

$$Q^2 = -q^2$$

the dimensionless variables x and y are defined by:

$$x = \frac{Q^2}{2pq}$$

$$y = \frac{pq}{pk}.$$

The strucure functions, $f_i(x, Q^2)$, of the quarks in the nucleons are taken from Ref. [6] by default. Other parametrizations of the structure functions are available (see Ref. [7]). They can be chosen overwriting flag LST(15) *after* the BEAMIN call (see below).
Note that the above cross section formula only takes into account purely electromagnetic effects. For beam-gas interactions, the invariant energy is sufficiently small that electroweak effects (i.e. Z^0 exchange) can be neglected.
In the Monte Carlo first x and Q^2 are sampled from the function $\frac{1}{xQ^2}$. Then x and Q^2 are sampled with the rejection method.

3. Description of the Flags and Cuts

Default values are given in brackets if present.

COMMON /BEADEF/ TMIN,TMAX

TMIN (0.1) minimum kinetic energy (in GeV) of the δ-electron for IOPT = 2,3

TMAX (15.) maximum kinetic energy (in GeV) of the δ-electron for IOPT = 2,3

Remark: TMIN cannot be chosen smaller than 10 MeV, TMAX must be smaller than the beam energy for the case of Bhabha scattering and smaller than half of the beam energy for the case of Møller scattering. This is due to the fact that masses are neglected in the above formulae.

COMMON /BEALUN/ LOUTBE

LOUTBE (6) logical unit number for output

COMMON /XINT/ NPOINT,NPX,NPY

NPOINT (100) Number of bins for the integration of the Rosenbluth formula (IOPT = 5 only).

NPX,NPY (50) Number of bins for the integration of the deep inelastic scattering formula (IOPT = 1 only).

COMMON /LEPTOU/ CUT(14),LST(40),PARL(30),X,Y,W2,Q2,U

CUT(1) (0.01)	minimum x
CUT(2) (1.)	maximum x
CUT(3) (0.)	minimum y
CUT(4) (1.)	maximum y
CUT(5) (4.)	minimum Q2
CUT(6) (1.E6)	maximum Q2
CUT(7) (5.)	minimum W2 (hadronic invariant energy)
CUT(8) (1.E6)	maximum W2
CUT(9) (1.)	minimum NU ($= \frac{Q^2}{2Mx}$)
CUT(10) (1.E6)	maximum NU
CUT(11) (1.)	minimum energy of scattered lepton for IOPT = 1
CUT(12) (1.E6)	maximum energy of scattered lepton for IOPT = 1
CUT(13) (0.)	minimum polar angle of scattered lepton for IOPT = 1,4,5
CUT(14) (3.1416)	maximum polar angle of scattered lepton for IOPT = 1,4,5

For detailed information please see LEPTO manual (Ref. [1]). Note that some options in LEPTO have been disabled. The structure functions are in agreement with LEPTO version 5.1 (see Ref. [7]).

4. Description of the Subroutines

SUBROUTINE BEAMIN(EBEAM,LEPIN,IOPT,IHIST,A,Z)

This is the initialization routine. It is initializes some variables and computes maxima of cross sections (for importance sampling technique).

input:	EBEAM	beam energy in GeV
	LEPIN	LUND code for incoming lepton
	IOPT	flag for the process to be simulated:
		= 1 deep inelastic lepton nucleon scattering
		= 2 Møller scattering
		= 3 Bhabha scattering
		= 4 Mott scattering
		= 5 Rosenbluth scattering
	IHIST	histogram level
		= 0 no histograms
		$\geq$ 1 book and fill default histograms
		$>$ 1 book, fill and print default histograms
	A	number of nucleons in current material
	Z	number of protons in current material
Remark:		the minimum beam energy allowed
		is 10 GeV (otherwise some
		approximations are no longer valid).

SUBROUTINE BEAMGA(IERR)

This is the main routine to simulate the process in question.

output: IERR error flag, if IERR > 0 an error has occured and no event has been generated

SUBROUTINE XCROSS(SIG)

This is the main routine to compute cross sections.

output: SIG cross section in nanobarns

SUBROUTINE BEAMEX

This is the termination routine. Required histograms will be printed.

5. How to Run the Program - Examples

The program (code and library) can be found in the KINGAL library on CERNVM and on VXCRNA.

5.1. Example: Compute the total cross section for Rosenbluth scattering

```
C
C COMMON block needed
C
      COMMON /LEPTOU/ CUT(14),LST(40),PARL(30),X,Y,W2,Q2,U
C
C define polar angle range [rad]
C
      CUT(13) = 0.001
```

```
            CUT(14) = 0.025
C
C beam energy [GeV]
C
            EBEAM = 45.
C
C incoming lepton is a positron
C
            LEPIN = -7
C
C define Rosenbluth scattering
C
            IOPT = 5
C
C we don't want to have histograms
C
            IHIST = 0
C
C define proton
C
            A = 1.
            Z = 1.
C
C initialize BMGA01
C
            CALL BEAMIN(EBEAM,LEPIN,IOPT,IHIST,A,Z)
C
C compute the cross section
C
            CALL XCROSS(SIG)
C
C and terminate BMGA01
C
```

```
      CALL BEAMEX
```

5.2. Example: Simulate Møller Scattering

```
      PARAMETER(LIMIT=5000)
C
C COMMON blocks needed
C
      COMMON /BEADEF/TMIN,TMAX
      COMMON /PAWC/ HMEMOR(LIMIT)
C
C initialize HBOOK
C
      CALL HLIMIT(LIMIT)
C
C define kinematic range for delta electron [GeV]
C
      TMIN = 0.1
      TMAX = 2.
C
C beam energy [GeV]
C
      EBEAM = 60.
C
C incoming lepton is an electron
C
      LEPIN = 7
C
C define Møller scattering
C
      IOPT = 2
```

```
C
C we want to have histograms printed out
C
            IHIST = 2
C
C define Oxygen
C
            A = 16.
            Z = 8.
C
C initialize BMGA01
C
            CALL BEAMIN(EBEAM,LEPIN,IOPT,IHIST,A,Z)
C
C simulate 1000 events
C
            DO 100 IEVENT=1,1000
C
                CALL BEAMGA(IERR)
C
  100 CONTINUE
C
C and terminate BMGA01
C
            CALL BEAMEX
```

6. The interface to GALEPH

The communication with GALEPH is done by the subroutines ASKUSE, ASKUSI and USCJOB. The input is to be supplied by the user via data cards. Most of the parameters already have been described in section 3. The data cards are organized as follows:

Data card BMGA: EBEAM LEPIN IOPT IHIST A Z DZ

DZ is the range in the z coordinate for smearing of the event vertex. It must be given in *cm*.

Data card BDEF: TMIN TMAX

Data card BLEP: CUTS(1) - CUTS(14)

This data card contains the array CUTS for the LEPTO program.

Data card XINT: NPX NPY (NPOINTS)

This data card contains the number of bins for the integration of the cross section if IOPT = 5, and it contains the number of bins in x and y if IOPT = 1.

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