Running Milagro and Milagrito Simulations with GEANT (Version 2.2)

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1 General Information

The GEANT version of the Milagro and Milagrito detector simulation can be found in the directory

/disk02/Milagro/simulation/milagro_geant_v22/

The directory contains the FORTRAN routines describing the detector, a makefile (Linux, Redhat 6.0), steering cards for choosing different options including baffles and the possibility to include an outrigger array. The same code is used for Milagrito and Milagro simulation, the only difference is in the tube positions and the water level, which have to be adjusted accordingly.
The detector design and the physics of the simulation are defined in two steering cards, *card* and *detector.txt*, which are described in more detail in the next sections.
In addition, the directory contains text files with the positions of pond tubes and outriggers for both detector setups: tube positions are read in from *milagritoSurvey.txt* for Milagrito, and *milagroSurvey.txt* for Milagro. If the simulation is to include outriggers, their positions are taken from the file *outrigger.txt*.
The *makefile* produces the executable *milagro* which needs the steering file *card*:

nice +20 milagro < card

Note: throughout the program, energies are in GeV, and times are in ns. The speed of light in vacuum is $c = 29.9792458\,\mathrm{cm\,ns^{-1}}$.

2 The Steering File: card

card contains basic information on the physics processes simulated. For standard runs, this file should not be altered. The meaning of (some) of the flags in card (1=on, 0=off):

- ckov (production of Cherenkov light)
- hadr (hadronic interactions)
- dray (δ-ray production)
- labs (Cherenkov light absorption)

The other parameters refer to physical processes like Compton scattering, pair production, bremsstrahlung. Please check the GEANT manual for details.
In addition, the user has to set

- cuts (cuts on the minimum energy (in GeV) for the different particle types)
- rndm (random number seeds).
- trig (number of particles in all events).

For running the program, make sure that the third *time* parameter is equal or greater than *trig*. With version 2.0, a major change has been introduced. In order to keep the allocated memory small, GEANT now treats particles one at a time. The parameter *trig* in card no longer represents the number of events to be generated, but the total number of *particles* to be simulated, summed over all events.
The number of events is now a parameter in *detector.txt*, and the *trig* parameter should be kept at a very high value so that the program never reaches the particle number given in *trig*.

3 The Detector Description: detector.txt

3.1 Detector type and PMT positions

The file *detector.txt* contains the information on the detector configuration. The first line is the CORSIKA file – the program is currently only accepting CORSIKA MC output as input. The second line is the name of the GEANT output file.
The third line allows to see particle tracking "live". This option is very interesting, but slow and may not work on all computers.
Both the detector type (Milagro or Milagrito) and the water/cover level have to be provided. If the cover level is higher than the water level, total internal reflection takes place all over the pond. If the Milagrito mode is chosen, the program uses the tube positions as given in *milagritoSurvey.txt*. For Milagro mode, the tube positions are taken from *milagroSurvey.txt*. The suggested water level is 670 cm and 180 cm for Milagro and Milagrito, respectively.
For both Milagro and Milagrito setup, baffles and outriggers can be added by setting the corresponding flags in *detector.txt*. If the outrigger option is chosen, outrigger positions are taken from the file *outrigger.txt*. All tube positions are in cm.
For Milagrito, tube numbers range from 1 to 239, the total number of tubes is 228.
For Milagro,

- air shower layer tube numbers range from 1 to 450 with a total number of 450 tubes,
- muon layer tube numbers range from 465 to 737 with a total number of 273 tubes.

Fig. 1 shows the tube positions in x and y for air shower and muon layer tubes in Milagro.
Outrigger numbers start at 1001. The default outrigger array in *outrigger.txt* has 352 outriggers with 10 m spacing on a 20×20 grid. The outriggers have a diameter of 243.84 cm and a height of 71.12 cm.
The program will skip a user-defined number of events if the first event parameter in *detector.txt* is not 1. In version 2.2, the total number of events has to be provided.
The output file contains only events with a minimum number of air shower layer tubes, but this parameter can be set to 0.

The detector simulation will produce an output file which, in addition to the pulse height and time information for every tube, holds some information on the particles entering the detector medium. All muons and hadrons are written to the output file, but for the much more abundant $e^{\pm}, \gamma$ a minimum energy has to be provided.

3.2 Effective Area and Core Position

For the range of core positions, two options are available:

1. The user can define a maximum range of core positions x_{max} and y_{max} for 4 different energy intervals (10 GeV to 100 GeV, 100 GeV to 1 TeV, 1 TeV to 10 TeV, and 10 TeV to ∞). The core is randomly thrown over an area $x_{max} \times y_{max}$ with the pond in the center.

2. The program automatically calculates x_{max} and y_{max} so that the throw area is proportional to the (energy-dependent) effective area A_{eff}. Fig. 2 shows the effective area of Milagro (top) and Milagrito (bottom) as a function of the primary energy for γ- and proton showers. For a given primary energy E, the core is thrown on an area

$$s \times x_{max} \times y_{max} = A^{\gamma}_{eff}(E), \tag{1}$$

where s is a user-defined scale factor.

In *detector.txt*, a scale factor $s = 0$ means that option (1) is chosen, and core ranges for the four energy intervals have to be provided. $s > 0$ means option (2) is chosen and the values for the 4 energy intervals are ignored. Note that for different trigger conditions and for other applications it may be appropriate to use a scale factor $\neq 1$. In order to keep track of the different core ranges, the output file contains x_{max} and y_{max} for *each* event.

4 The Output Format(s)

The GEANT output is ASCII and contains the following information for each event:

- first line (4 parameters):
  - primary particle type, e. g. 1 (γ), 14 (proton),
  - energy of the primary particle in GeV
  - incident angles θ and ϕ in radians
- second line (4 parameters):
  - true core position (x, y) *at water level* in cm,
  - core range $(x, y)_{range}$ in cm,
- third line (3 parameters):
  - height of first interaction in cm
  - number of particles reaching the ground
  - number of particles entering the pond water
- fourth line (1 parameter):

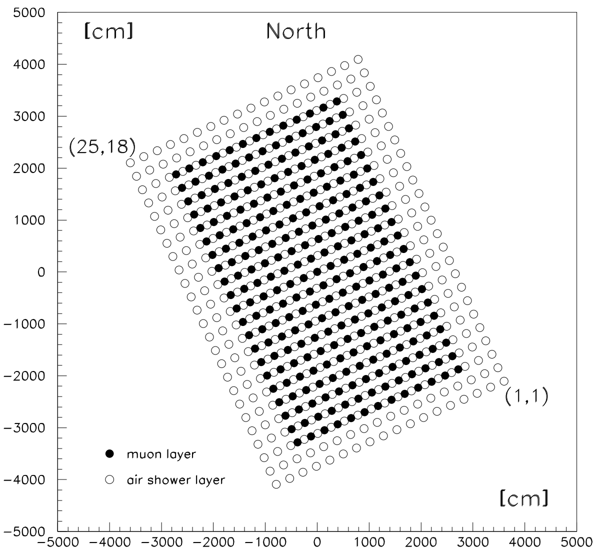

Figure 1: Tube positions in x and y for air shower and muon layer tubes in Milagro.

- number n of tubes (sum of all layers, including outriggers)

- n lines giving the tube information: tube grid number, number of PEs, tube time including a tube jitter simulation, tube time without jittering,
- number n_{part} of particles entering the water (including outriggers). This includes *all* muons and hadrons, and additionally all $e^{\pm}, \gamma$ with energy larger than the minimum energy given in *detector.txt*
- n_{part} lines giving the particle information: particle identity, energy in GeV, θ and ϕ in radians, and position (x,y) *at water level* in cm. For the particle identity, please check the GEANT or CORSIKA manual - the most common numbers are 1 (γ), 2 (e^+), 3 (e^-), 5 (μ^+), 6 (μ^-).

The azimuth angle ϕ is given with respect to true East, measured counter-clockwise. The tube times are in nanoseconds. The first tube time is set to 1.0 ns (arbitrary) and all other times are with respect to the first tube.

To read Milagro showers generated with version 2.2, it is necessary to set

$$\text{dataCon.source} = \text{DATA\_MCASCII3} \tag{2}$$

in the analysis program. The tube information is then stored in the CAL_DATA structure (see Reconstruction.h). Additional information is in the MONTE_DATA structure. Currently, the following information is stored:

- short int nPMTs (number of PMTs)
- short int MONTE (1 for MC, 0 for experimental data, necessary for event display)

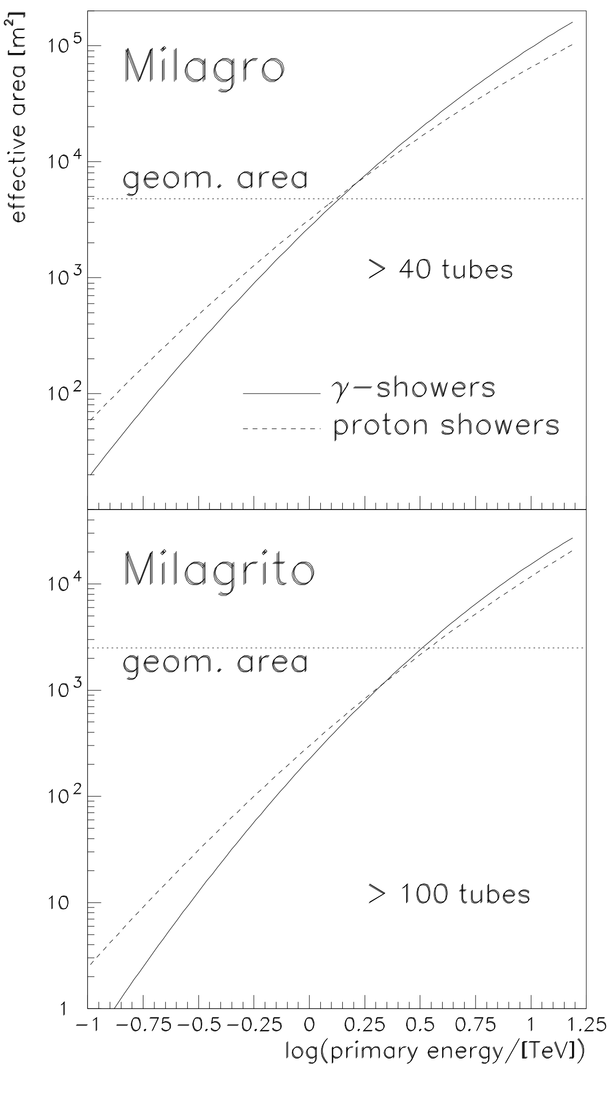

Figure 2: Effective area vs. primary energy for Milagro (top) and Milagrito (bottom) for zenith angles $0^o \leq \theta \leq 45^o$.

- unsigned int eventNum (event number)
- unsigned int partId (particle identity)
- unsigned int nShowerMC (total number of shower particles)
- unsigned int nPondMC (total number of shower particles entering the detector medium)
- float thetaMC, phiMC (true zenith and azimut angle in rad)
- float ePrimary (energy of the primary particle in GeV)
- float fintHeight (height of the first interaction in cm)
- float xCoreMC, yCoreMC (true core position in cm)
- float xRangeMC, yRangeMC (core throw area range in cm).

In addition, the structure MUON_MC is filled with the following information:

- short int nMuonMC (number of particles written to the output file (see above))
- short int muonID[i] (identity of particle i, i ranging from 0 to (nMuonMC-1))
- float muonEnergy[i], muonXMC[i], muonYMC[i], muonTheta[i], muonPhi[i] (energy, position in x and y, direction (θ, ϕ) of particle i).

5 Currently Used Parameters

The parameters currently used in the code are summarized in Fig. 3 and Table 1. All parameters in Tab. 1 could in principle be implemented wavelength-dependent, if measurements existed.
The absorption probabilities are stored in the subroutine *ugeom.f.* For changes in the default type of the quality of the surface finish (perfect smoothness, maximum roughness, or anything in between), check subroutine *guplsh.f.*
The simulation of the water (absorption length, scattering length, and type of scattering) will only be changed if sufficient experimental evidence and information is available.

material	abs. prob.	ref. type
Pond bottom	0.95	diffuse
Baffle (inside)	0.2	specular
Baffle (outside)	0.95	diffuse
PMT (lower sphere)	0.1	specular

Table 1: Default values for material reflection properties. See Fig. 3 for wavelength-dependent material properties.

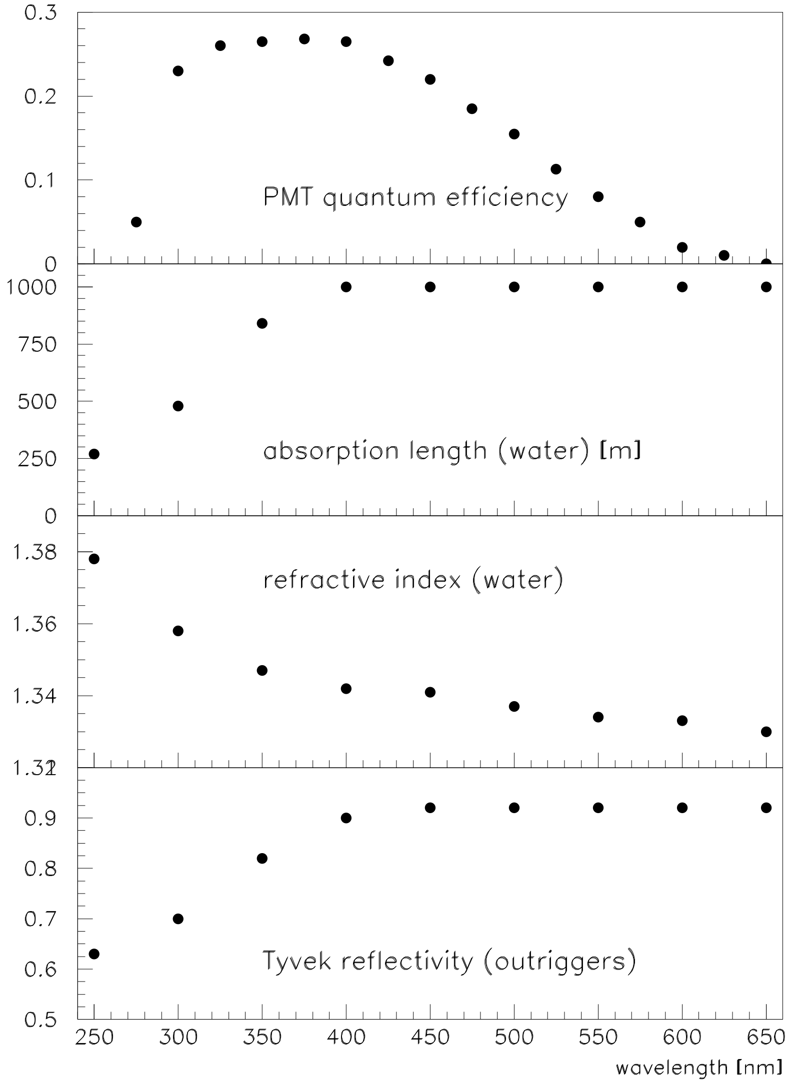

Figure 3: Wavelength dependence of PMT quantum efficiency, water properties (absorption length and refractive index), and Tyvek reflectivity.

6 Muons and Hadrons

The subroutine *getparticle.f* can currently only handle CORSIKA input. An additional routine *getpart_hadron.f* is supplied which allows to simulate *single* particles. This version can be found in

/disk02/Milagro/simulation/milagro_geant_v11/specials

together with an additional data file *hadron.txt* and a makefile. This routines allows to throw single muons and hadrons on a spectrum or with fixed energies. Refer to the CORSIKA or GEANT manual for the particle identities if different from 1 (γ), 2 (e^+), 3 (e^-), 5 (μ^+), 6 (μ^-), or 14 (protons).

7 CORSIKA and GEANT manuals

The CORSIKA and GEANT manual pages are available online:

- CORSIKA: http://ik1au1.fzk.de/~heck/corsika
- GEANT: http://wwwinfo.cern.ch/asd/geant/index.html