TRIUMF Experiment E614
Technical Note 33

Cosmic Rays: a GEANT routine and calibration uses

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20 July 1999

Abstract

Cosmic rays can be used to calibrate the positions of the wires in the drift chambers. The major advantages of using this method, rather than (or in conjunction with) a beam, are accurate determination of wire positions away from the beam axis, and the ability to run the experiment without using up beamtime. This analysis was carried out using E614 GEANT v1.2, to which a cosmic ray generator was added, which will be available as part of the next version. The simulation showed we should be able to determine the position of the wires in the assembled detector to an accuracy of 10 microns within about 5 to 6 days.

Using the cosmic generator

The cosmic ray generator is used in exactly the same way as the four initial kinematics options already implemented. The user input file `e614.ffcards` can contain the COSM entry which is analogous to the MONO, BEAM, DOSP and RAYS, for example:

```
COSM 1 1000.0 200000.0 145.0 -345.0 345.0 -145.0 145.0
```

1 : This is a flag to turn the generator on or off. Enter a negative integer to turn off, a positive one to turn on. Only one initial kinematic generator is allowed on at once.

1000.0 : The minimum momentum allowed for the cosmic ray muons, in MeV/c.

200000.0 : Maximum momentum allowed for the cosmic muons.

145.0 : Window height above detector axis, ie in y, units cm. (see below)

-345.0, 345.0: Z-coordinates of ends of window.

-145.0, 145.0: X-coordinates of end of window.

When called at the start of an event, the generator randomly places a muon in the 'window' specified above, with the required direction and momentum distributions typical of a cosmic ray. The muon could have either positive or negative charge.

Details of the cosmic generator

Muons will constitute about 99 percent of the cosmic ray flux into the detector; at the moment these are the only particles incorporated into the generator. The ratio of μ^+ to μ^- is set at 1.25 to 1, which approximates the actual distribution. The differential momentum distribution is modeled as proportional to the inverse square of the momentum, which is approximately true. The angular distribution is cos^2 of the zenith angle. [3]

In practice, the window described above will be the upper surface of a scintillator placed on top of the detector once it is assembled. When a cosmic ray passes through the scintillator, it triggers the other detectors to record the event; we are only interested (at present) in simulating the cosmics which we can trigger on.

The following source files were modified from version 1.2:

```
apffky.F
gukine.F
uginit.F
ukin.inc
( e614.ffcards )
```

`gukine.F` contains most of the code for the generator.

The algorithms used were adapted from the MEGA simulation. Tests against simple rejection algorithms showed them to be just as accurate but about half as fast again. The zenith angle routine is a form of iteration, the momentum a direct formula. If more complicated distributions were to be modeled in the future I would suggest using a rejection algorithm as the iteration would be more difficult to modify.

Limitations of generator

The energy of the simulated cosmics is highly sensitive to the minimum momentum specified in the `.ffcards` file. This minimum momentum is sensitive to the immediate surroundings of the detector, and in reality there is no sharp cut-off point as the model suggests. However I do not think the exact momentum distribution is essential for our needs at present; this model and the minimum momentum value suggested above seem reasonable approximations.

The model assumes independent distributions for the angle and the magnitude of the momentum. This is a fair approximation for most of the cosmic rays, but at large (near-horizontal) angles more energetic cosmics are more common, and for high energy cosmics (beyond a couple of hundred GeV) the distribution changes from cos^2 and approaches sec of the zenith angle. However, these very high energy cosmics were considered fairly unimportant for the purpose of our simulation.

The detector, when in the experimental hall, will be housed 2 stories underground and so high-angle cosmics will have to penetrate the earth surrounding the hall to reach the detector. The angle, from horizontal, from the detector to the earth surrounding the meson hall, is about 20 degrees or less; a reduced flux from this region is not serious.

Use for calibration

Cosmic rays propagating through the chamber behave predictably, the majority not noticeably affected by the chamber materials, and so going in straight lines (field off) or portions of helices (field on). Using drift chambers we can fit the track (to a straight line or curve), by comparing this fit against the actual response we can get a better estimate of the position of the wires in the drift chambers. To determine the position of the wires when the tracks are straight lines, i.e. field off, to an accuracy of 10μm requires 5000 hits per wire, with the cosmic ray passing through at least 5 pairs of drift planes (5 independent measurements of x,y) [figures from Maher Quraan]. With the field on, more pairs are needed for curve fitting, but the exact figures have not as yet been looked into, maybe 6 or 7 pairs.

The following analysis assumes we have the field off.

GEANT simulation of cosmics

The results of 700000 hard cosmic rays incident on the detector are displayed in Figure 1 and Table 1 at the end of this note. This number of cosmic rays corresponds to about 270 seconds of exposure. The GEANT version was E614 v1.2. The simulation was run with the following COSM line in `.ffcards`:

```
COSM 1 1000.0 200000.0 145.0 -345.0 345.0 -145.0 145.0
```

The number going through 10 or more planes (ie 5 pairs) in 269 seconds is 777, or 2.9 useful cosmics per second. For the number of wires we have, each cosmic helping to position on average 11 wires, it would take 5 to 6 days to get the 5000 per wire needed. This assumes each wire is equally hard to position, which is not strictly true; the end drift chambers have fewer cosmic rays passing through them that also pass through four other pairs. However at each end there are 6 planes clustered together, so this effect will be diminished.

Possible complications

The above analysis is done with the magnetic field off. It would be desirable to do the analysis with the field on, as this is the state we will have the detector when we do the measurements of muon decay. If we need 6 pairs to fit the track, that will take us up to 13 to 14 days of running time; 7 pairs about a month. Even though this prolongs the calibration time by a fair amount, this is not inconceivable.

The angles that the scintillator and ground level in the meson hall subtends at the detector are about the same; this means we are receiving about the same about of useful flux than if the detector was at ground level.

No. of drift chambers crossed	No. of cosmics
0	691399
1	812
2	3004
3	479
4	1417
5	447
6	682
7	328
8	509
9	146
10	368
11	89
12	138
13	51
14	77
15	20
16	15
17	8
18	6
19	1
20	2
21	0
22	1
23	1

Table 1: 270 seconds of cosmic rays

The iron yoke, present in the final detector arrangement, is not yet simulated in GEANT. However the cosmic rays are energetic enough to pass through 6 to 10 inches of steel without losing too much momentum (mean range is approximately [500cm times energy in GeV]), so the flux will not decrease by any significant amount due to the yoke.

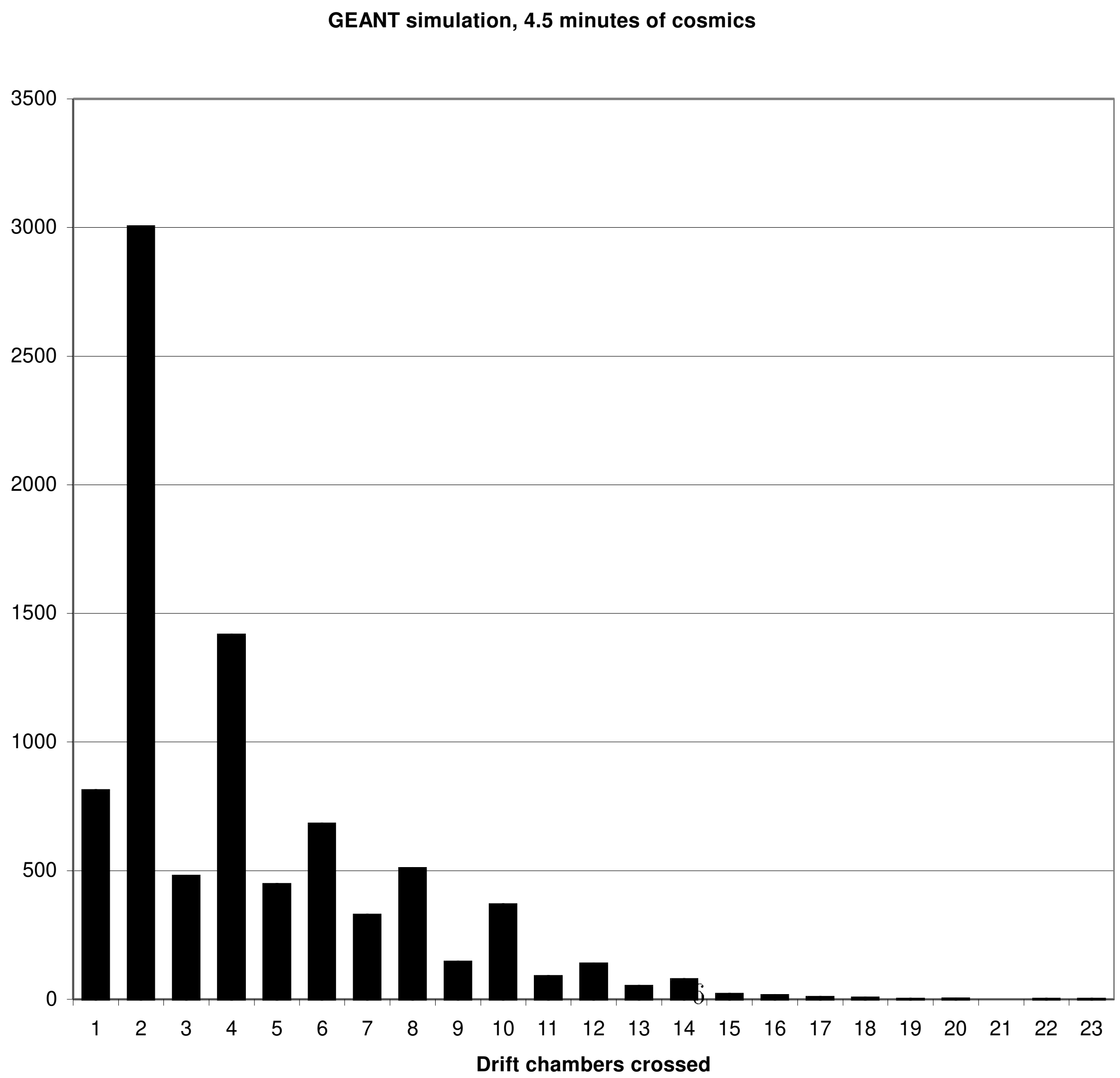
At the moment the situation being modeled has a scintillator sitting on top of the detector. This doesn't trigger on near horizontal particles which are potentially useful (however the flux of these particles is low, due to the cos^2 distribution and the earth surrounding the building). Additional scintillators could be placed around the detector to trigger on these cosmics. The number of useful particles added by this method is harder to simulate than the above, but could be looked into if we want to fit curves and we are on the boundary of the technique being feasible in terms of the amount of time needed to get 5000 per wire. At the moment my view is that it is shown that we can get good statistics from the scintillator on top, if we put additional scintillators to the sides that is a bonus.

References

[1] GEANT Version 3.21, CERN, Geneva 1993.

[2] TN-29 E614 GEANT user's guide

[3] Particle Data Group 1998 Review of cosmic rays (`http://pdg.lbl.gov/`)


GEANT simulation, 4.5 minutes of cosmics
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Drift chambers crossed