SDC-92-300

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SOLENOIDAL DETECTOR NOTES

A CASE STUDY ON THE EFFECT OF COMPUTATIONAL PRECISION ON GEANT SIMULATIONS

August 13, 1992

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A case study on the effect of computational precision on GEANT simulations

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13 August 1992

ABSTRACT

We have used a simulation of the passage and scattering of muons through the rock overburden of the Soudan 2 experiment to investigate the effect of computational precision on the predictions from GEANT simulations. The observables used are the mean differential energy loss and the positional and directional deflections of high energy muons passing through 700 m of rock, geared towards irreducible measurement uncertainties in muon astronomy studies being and to be performed with the Soudan 2 experiment. We find that the double precision version of the code reproduces the existing single precision results very well.

In two previous notes[1,2] the total energy of atmospheric muons passing through the rock overburden into (and through) the Soudan 2 cavern and the distributions of position and direction upon entrance into the Soudan 2 cavern has been studied. The simulation program we have used is based on the GEANT[3] package version 3.14. Recently, double precision versions of the basic CERN libraries and GEANT 3.15 have been prepared using the precision doubling feature of the Fortran compiler on the IBM RS6000 series of work stations.[4] Because of the simplicity of our program for the muon passage studies, we have rerun the program with identical user input both with GEANT 3.14 in normal precision (there are a few routines and sections in GEANT coded explicitly in double precision) and GEANT 3.15 in doubled precision.

The observables of choice are the differential energy loss for muons in Soudan rock as a function of energy and the distributions of position and direction of the muons after passing through 700 m of rock. The first of these we expect to be fairly insensitive to the computational precision because it comes from the *user* part of the program which is in this instance written in double precision already. Differences at this point would imply that the two versions of GEANT in use here would give different results on a single step basis already, rendering the whole comparison with respect to computational accuracy invalid. The other two are determined completely by the internal precision of GEANT, piling up computational errors over more than 10000 steps of a few centimeters length (on average, Fig.1) and looking for dimensions at a 10^{-3} level relative to the dominating dimension of 700 m. The incident muons are taken to form a pencil beam, *i.e.* they are incident at a fixed point $(0, 0, 700)$ m with the direction $(0, 0, -1)$. The energy spectrum of the muons is taken to have a shape $dN/dE \sim E^{-3.71}$ corresponding to the observed cosmic ray muon spectrum at the earth's surface. The energy is chosen according to this spectrum in the interval 500 GeV to 100 TeV. The lower limit is chosen as a value up to which all muons will definitely be stopped in less than 700 m of Soudan rock, and the upper limit is needed to reproduce[1] the measured energy spectra at the site of the NUSEX experiment,[5] located more

than twice as deep under rock as the Soudan experiment. The random generation starts from a $x^{-1.0}$ distribution followed by a $x^{-2.71}$ weighting procedure to get acceptable statistics at high energies. In histograms where numbers of events are counted, the weights are used to get the shape correct; consequently, the apparent fluctuations are not determined by the number of events in a bin shown. All physical processes GEANT is capable of simulating explicitly are used to get the scattering of the muons as realisticly as possible. For multiple Coulomb scattering, the Molière scattering simulation is used throughout (GEANT's default is a mixture of this and a Gaussian approximation which is not accurate enough[2]). Secondary particles are generated with kinetic energies down to 100 keV except photons which are allowed down to 10 keV. This is done to ensure that the muons collect all momentum transfers in three dimensions; the secondaries are otherwise immediately removed from the simulation. The production of δ rays representing the discrete version of the high–energy tail of the ionization energy loss is used down to 1 MeV kinetic energy of the δ electrons; the Landau fluctuations of the ionization energy loss are accordingly restricted. This threshold energy does not noticeably affect the distributions of position and direction of the muons while saving some computing time* as the δ electron production dominates the mean free path of the muons in the simulation.

The doubled precision calculations reproduce the distributions of the differential energy loss over the incident energy (Fig.2), the positional deviation measured radially (squared variable r^2) in the plane transverse to the incident beam direction (Fig.3) and the direction measured by the angle (squared as θ^2) against the incident direction (Fig.4) very well. Although the fitting of Gaussians with central value zero (Fig.5) leads to somewhat different results in the case of the r^2 distributions, the actual distributions are essentially undistinguish-

* In the previous studies,[1,2] we had set the threshold by default at the lowest kinetic energy for transporting electrons, *i.e.* 100 keV. In the second of these, we have looked at the effect of using 10 MeV as the threshold instead of 100 keV for δ rays and found a change of their contribution to the muon deflections of no more than 10 percent. At 1 MeV, it is barely observable and totally negligible compared to the dominating multiple scattering effect.

able. The change of the fit results is easily inferred by statistical fluctuations. As mentioned earlier, the event generation produces weighted events, thus the same number of entries in two different bins corresponds in general to different numbers of generated events, and the rarer events at higher energies, despite the weighting, produce on average smaller values of r^2 and θ^2.

In conclusion, we have investigated the influence of the computational precision, *i.e.* internal storage size for REAL numbers, on a particular, fairly extreme simulation using GEANT. In this case, GEANT proves to be quite insensitive to the limited precision of the number representation in 32 bit words. Therefore, trouble should start only when one comes much closer to the limit of the number representation, *e.g.* when looking for microns over distances of meters.

ACKNOWLEDGEMENTS

We are indebted to Drs. Roethlisberger, Aubry and colleagues at CERN for providing the doubled precision CERN program libraries to us, and to the Dederal Sector Division of IBM at Houston, Texas, foremost Mr. Anthony Elam and Mr. James West, for making an IBM RS6000 model 320 workstation available to us and for helping to get going quickly on it. This work has been supported in part by the Department of Energy under grant no. DE-FG05-91ER40633.

REFERENCES

1) H.-J.Trost, Simulation of the passage of muons through the rock overburden into the Soudan 2 cavern, PDK 473 and ANL/HEP/TR-91/56, Argonne National Laboratory, 3 July 1991

2) H.-J.Trost, On the scattering of atmospheric muons in the rock above Soudan 2

3) R.Brun *et al.*, GEANT 3, CERN DD/EE/84-1, version 3.14.16, CERN, Geneva, Switzerland 1990, with corrections collected up to July 31, 1991

4) M.Roethlisberger, P.Aubry *et al.*, CERN, private communcation

5) M.Calicchio *et al.*, Phys.Lett. 193B (1987) 131

FIGURE CAPTIONS

1. Distributions of a) log_{10} of step lengths, b) log_{10} of energy loss per step, and c) log_{10} of number of steps per event

2. Differential energy loss in GeV/cm over $log_{10}(E/GeV)$ for muons in Soudan rock

3. Distribution of the squared transverse radii of muon positions after passing 700 m of Soudan rock

4. Distribution of the squared opening angle of the muons against the incident direction after passing through 700 m of Soudan rock

5. Distributions of r^2 and θ^2 fitted with functions $e^{P1} \cdot e^{-P2 \cdot x}$ with $x = r^2, \theta^2$

Muon passage through rock above Soudan 2

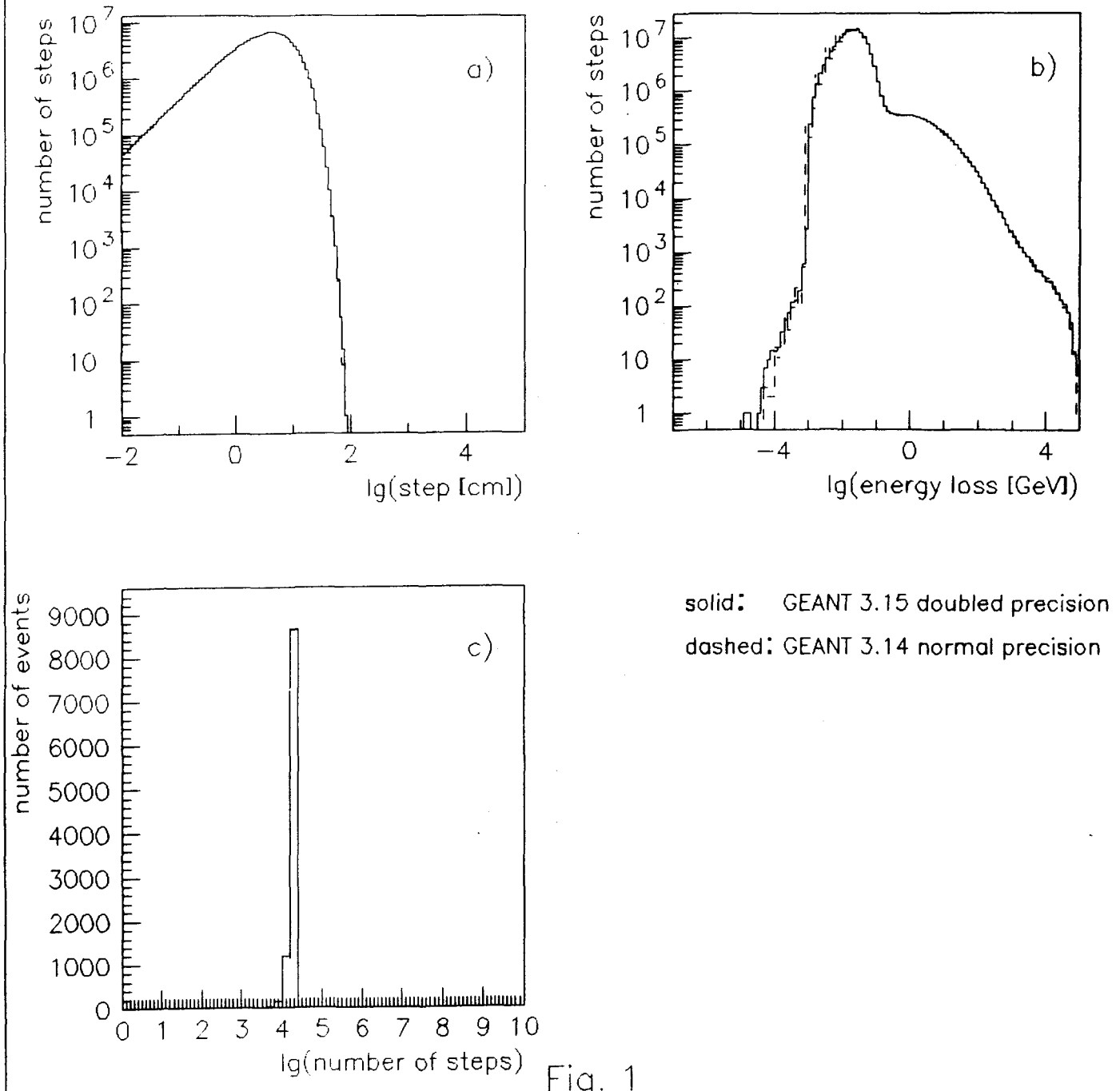


Fig. 1

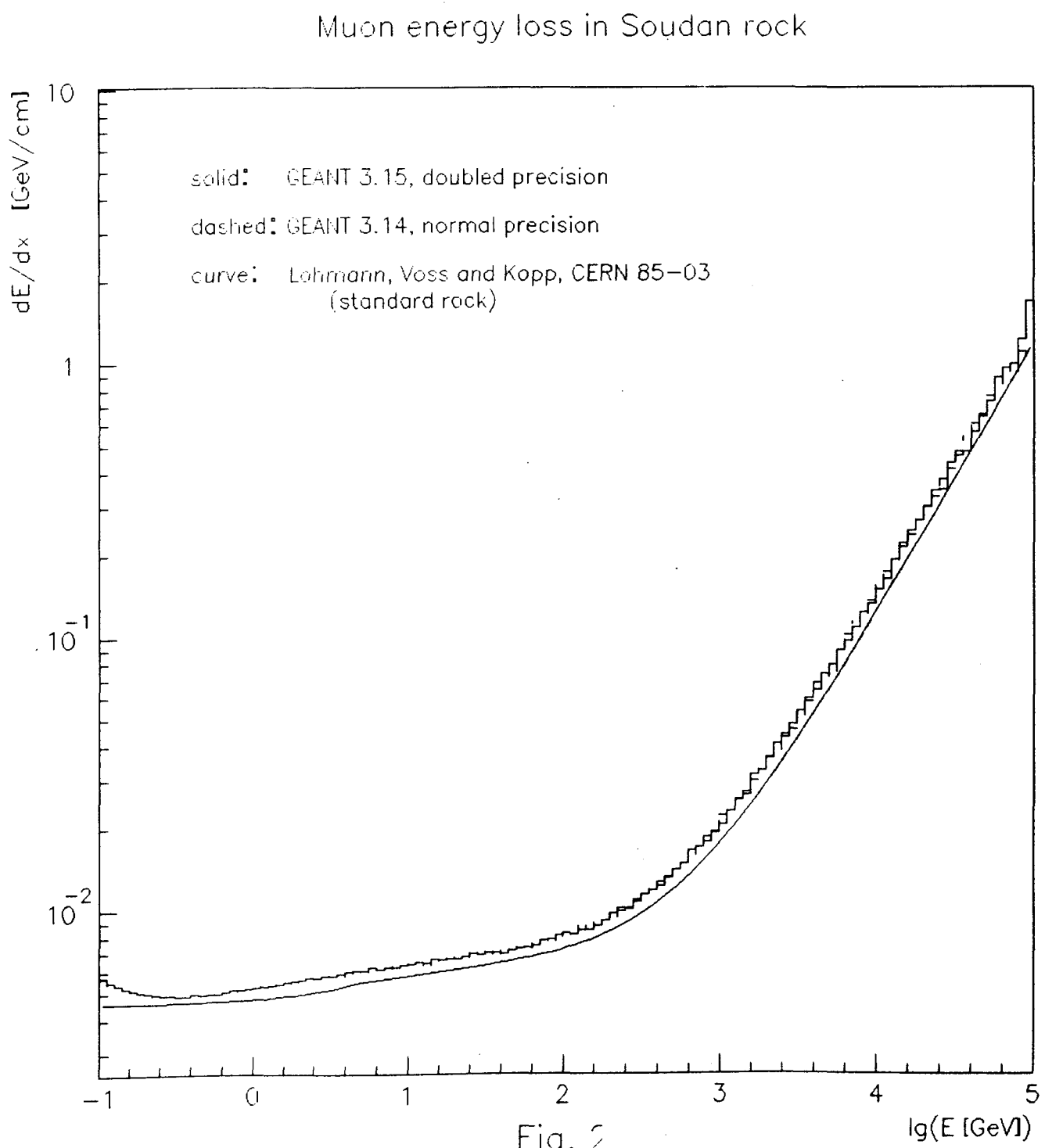

Muon energy loss in Soudan rock
dE/dx [GeV/cm]
10
1
10^{-1}
10^{-2}
solid: GEANT 3.15, doubled precision
dashed: GEANT 3.14, normal precision
curve: Lohmann, Voss and Kopp, CERN 85-03
(standard rock)
-1
0
1
2
3
4
5
lg(E [GeV])

Fig. 2

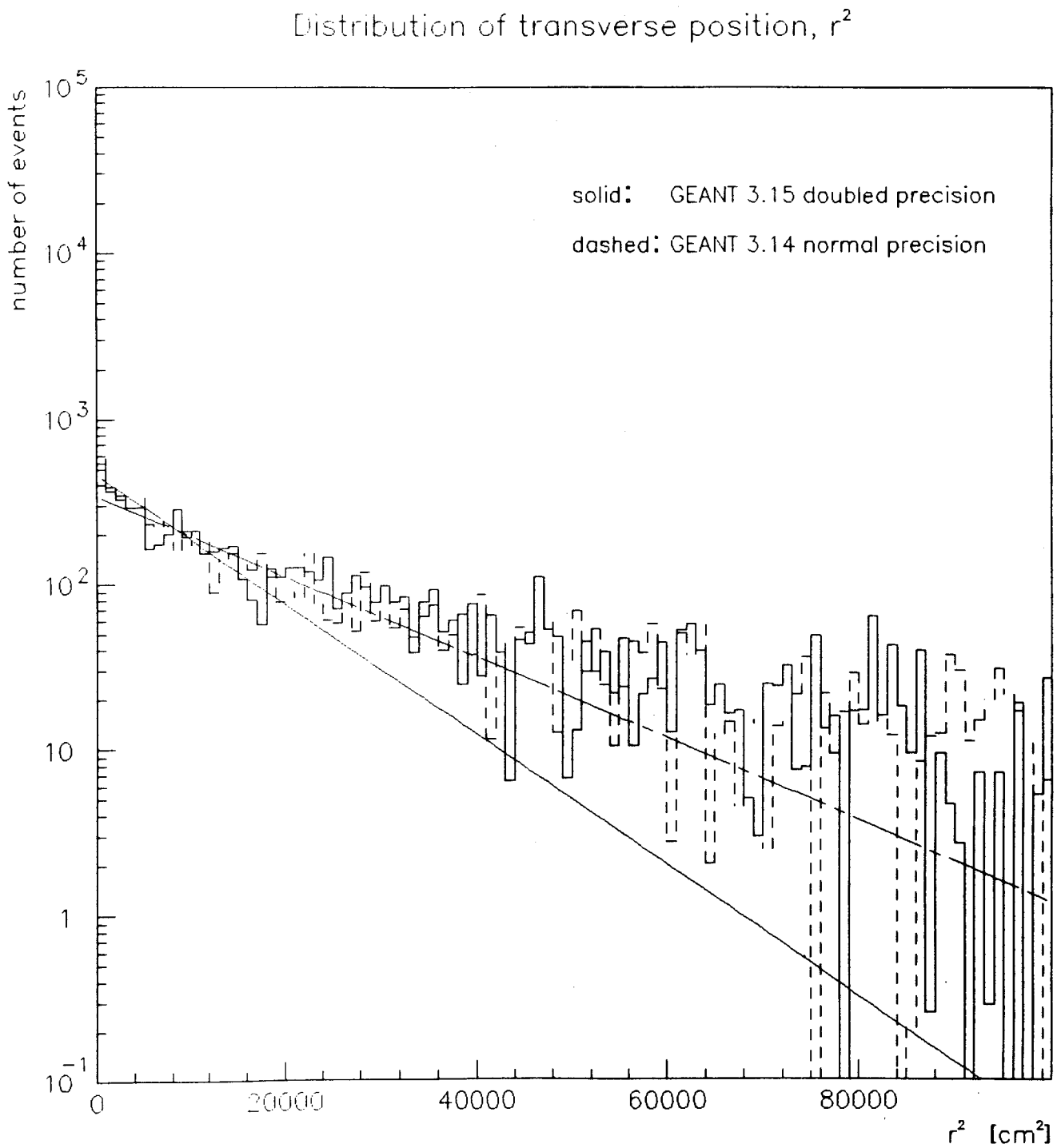

Distribution of transverse position, r²
number of events
solid: GEANT 3.15 doubled precision
dashed: GEANT 3.14 normal precision
10⁵
10⁴
10³
10²
10
1
10⁻¹
0
20000
40000
60000
80000
r² [cm²]

Fig. 3

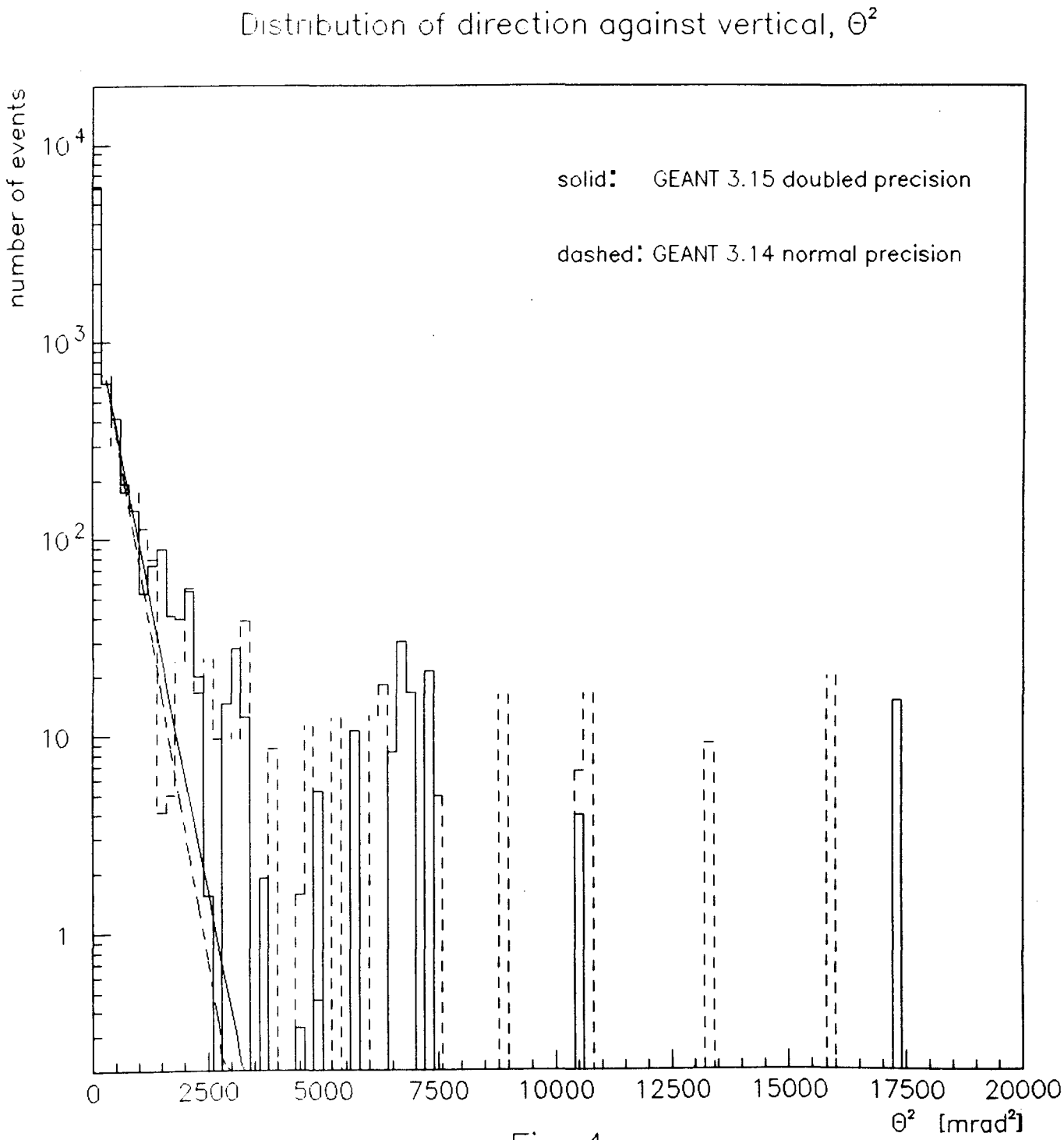
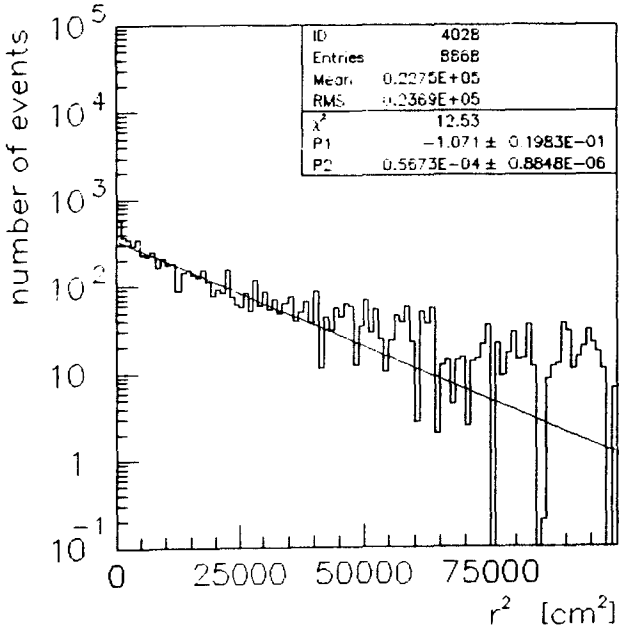
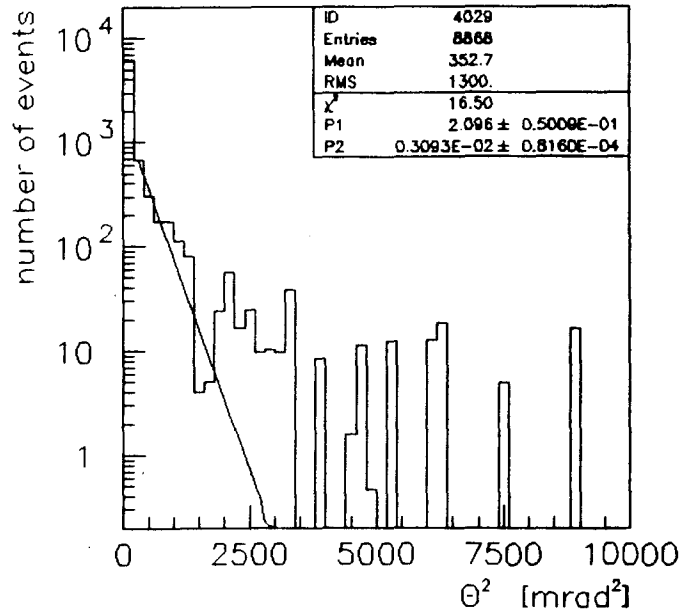

Distribution of direction against vertical, Θ²
number of events
10⁴
10³
10²
10
1
solid: GEANT 3.15 doubled precision
dashed: GEANT 3.14 normal precision
0
2500
5000
7500
10000
12500
15000
17500
20000
Θ² [mrad²]

Fig. 4

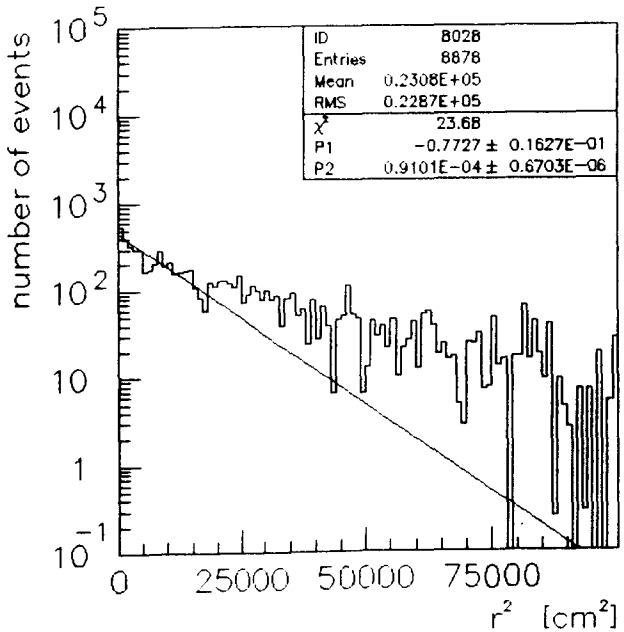
Fits for $\langle r^2 \rangle$ und $\langle \Theta^2 \rangle$

GEANT 3.14 normal precision





GEANT 3.15 doubled precision



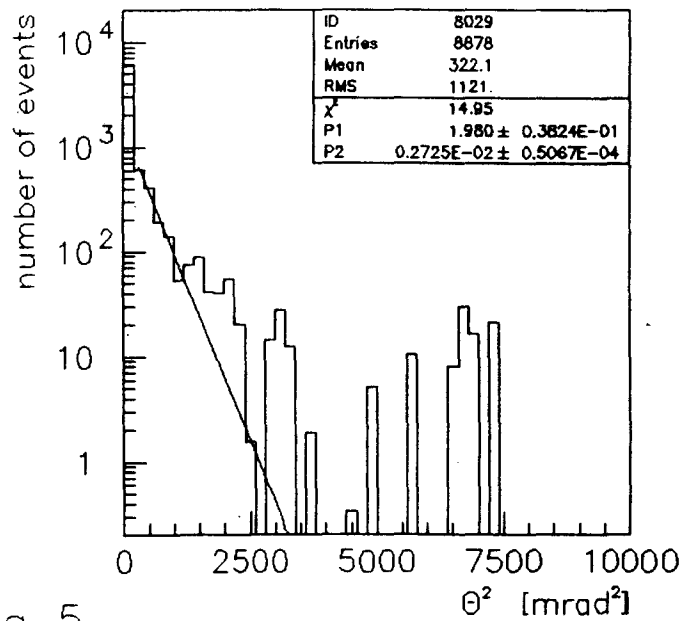


Fig. 5