

# ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Pavia

---

INFN/BE-88/3

6 Aprile 1988

Paolo Pedroni:

SIMULATION OF INELASTIC HADRON COLLISIONS BELOW 5 GEV: A MODIFICATION  
OF GEANT3 PACKAGE.

SIMULATION OF INELASTIC HADRON COLLISIONS BELOW 5 GEV:  
A MODIFICATION OF GEANT3 PACKAGE

INFN/BE-88/3

6 Aprile 1988

Paolo PEDRONI

Istituto Nazionale di Fisica Nucleare, Sezione di Pavia

ABSTRACT

To evaluate the detector characteristics in an experiment designed to study photoproduction and photodisintegration at energies above pion production threshold at the Saclay linear accelerator (ALS), a Monte Carlo simulation program has been written. We used the CERN FORTRAN package GEANT3 which has been modified to correctly generate hadronic interactions of particle with momenta below a few GeV. In this note we describe our simulation program in which GEANT3 has been corrected with the addition of a new hadronic library. We provide some comparisons between simulated and experimental data for our detector.

## 1. INTRODUCTION

The GEANT3 code (ref.1) was developed to track particles in a user's defined experimental setup to study its acceptance and geometry as well as to simulate and analyze its response. From the program sections (e.g. geometry description, events generation, particle tracking, trajectories recording, etc.) the user selects and assembles an executable program of the appropriate segments and tools by coding relevant subroutines, providing data parameters describing his experimental apparatus and controlling the event flow.

The hadronic interactions subroutines grouped in GHEISHA library (ref.2) are of particular interest to us. GHEISHA is not directly linked to GEANT3 as these two codes are not completely compatible: some interfacing routines generate hadronic interactions according to GHEISHA but preserve GEANT3 philosophy for tracking. These subroutines initialize GHEISHA constants (subroutine GHEINI), and hadron-proton cross sections starting from tabulated data on non-strange baryons (subroutine CSDATA), calculate hadron-nucleus cross sections (subroutine GHESIG) and finally switch to the cascade routine of GHEISHA treating the particular interaction previously selected (subroutine GHEISH). This program was made principally to handle high energy physics multihadron cascades and such algorithms are not relevant below energies of a few GeV. An inelastic interaction, for instance, generates many secondary particles and a final conservation energy check which would slow down greatly the execution speed; therefore this conservation is not explicitly verified, with the resulting discrepancies being within experimental errors ( $\cong 10\%$ ).

At low energies events are less complicated and errors too big: as it is seen in Fig.1, where the simulated response of an ideal infinite plastic scintillator (made of carbon and hydrogen) to 700 MeV/c protons is plotted, non conservation is more than 100 %. From the plots of the number of emitted cascade nucleons and of the proton-to-neutron ratio (Fig. 2 and 3) we see that baryon number and electric charge are not conserved as there are events with more than 12 emitted nucleons (while the largest target is  $C^{12}$ ) and furthermore that more final state protons than neutrons are emitted (with many cascade events containing only protons: among  $\cong 12500$  cascade events only  $\cong 3100$  have secondary neutrons) in contradiction to experimental evidences.

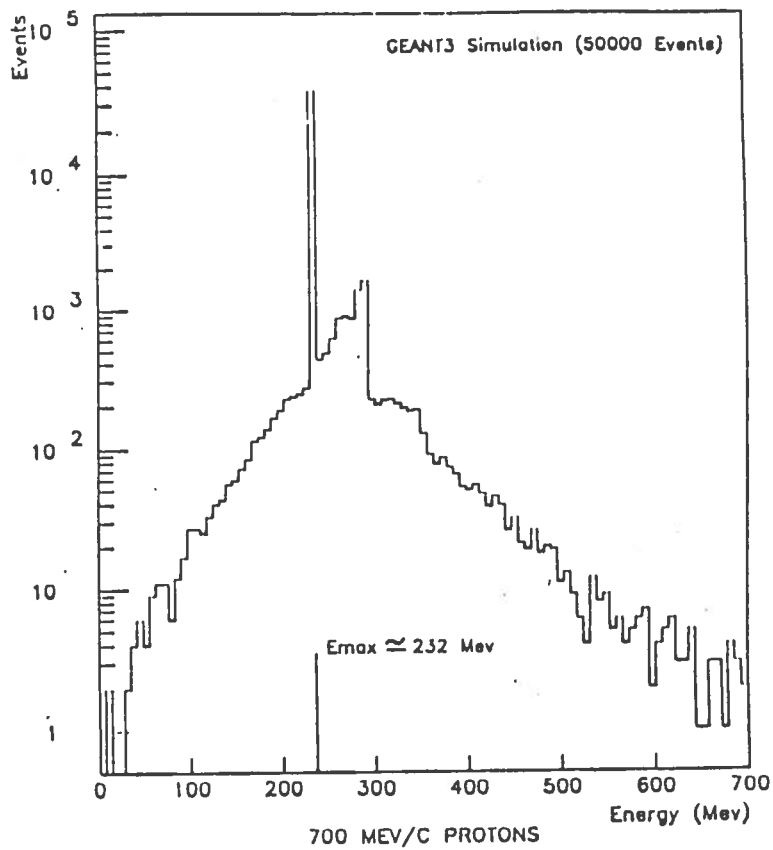


Fig. 1. GEANT3 simulated response of an ideal plastic scintillator to 700 Mev/c protons.

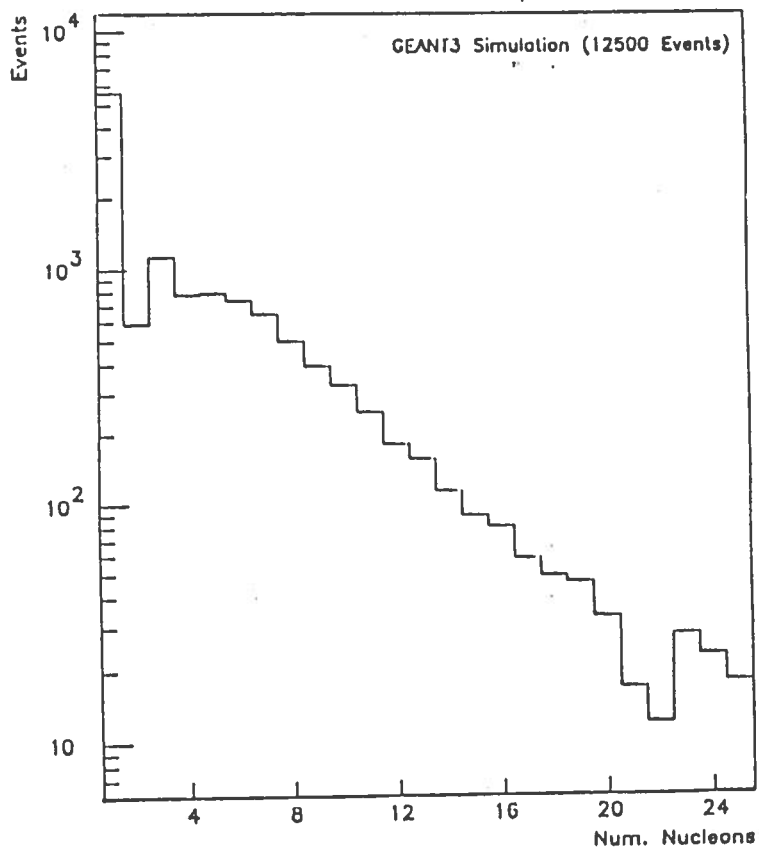


Fig. 2. Number of emitted cascade nucleons per event.

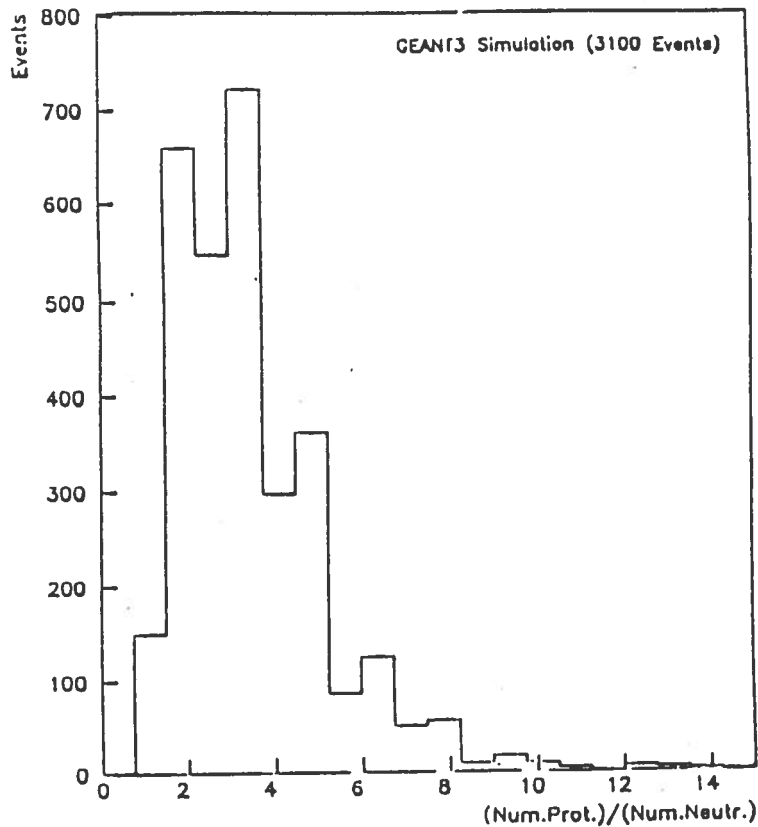


Fig. 3. Proton-to-neutron ratio.

Similarly for pion induced interactions at the same energies, charge exchange reactions:



which give an important contribution to inelastic cross section are greatly underestimated.

Because it is very difficult a correction "a posteriori" of each sampled event and, on the other hand, it is desirable to continue to use GEANT3 geometry and particle tracking routines, we have modified the hadronic generation section introducing in GEANT3 the codes HADRIN and NUCRIN that properly simulate hadron-nucleon and hadron-nucleus interactions at energies below a few GeV.

## 2. THE HADRIN SUBROUTINE

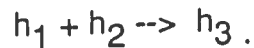
HADRIN (ref.4) simulates hadron-nucleon interactions from the pion production threshold up to about 5 GeV in laboratory energy. The corresponding physical model is based on the experimental evidence that inelastic cross section shows, in this range, a threshold and a resonance behaviour: the primary hadron-nucleon system is excited to an isobaric state which then decays into hadrons or other resonances. Two reaction channels are therefore possible:

a) Quasi two body production:



with  $h_3, h_4$  being particles, resonances or charge conjugated states ;

b) Direct resonance production :



For events generation the program uses the code DECAY (ref.5) in which the decay modes of 97 particles and resonances, produced in h-nucleon reactions (with  $h = \pi^0, \pi^+, \pi^-, k^+, k^-, \bar{k}^0, k^0, \bar{p}, p, \bar{n}, n$ ) into 350 different channels are tabulated and in HADRIN 10 further resonances and 100 decay channels are additionally included.

Outgoing particle directions and momenta are chosen to reproduce experimental momentum transfer distributions (ref.6) and generated events conserve energy, momentum, electric and baryonic charge and strangeness. HADRIN is initialised by the user with a call to the subroutines HADDEN and CHANWH which establish, before the beginning of the simulation, program internal weight tables for DECAY's reaction and decay channels. Hadron-nucleon (assumed at rest in laboratory system) interactions are generated by the instruction :

```
CALL HADRIN (N,PLAB,ELAB,CX,CY,CZ,ITTA)
```

in which the projectile is specified by particle type (N), momentum in GeV/c (PLAB), total energy in GeV (ELAB), direction cosines (CX,CY,CZ) and target nucleon type is ITTA. The result is a table of stable secondary hadrons whose characteristics are stored in the COMMON-block FINLSP:

COMMON/FINLSP/IR,ITR(20),CXR(20),CYR(20),CZR(20),ELR(20),PLR(20)

where each lth produced particles (whose number is IR) has a code number ITR(l), a total energy ELR(l) (GeV), a momentum PLR(l) (GeV/c) and direction cosines CXR(l), CYR(l), CZR(l).

### 3. THE NUCRIN SUBROUTINE

NUCRIN (ref.7) simulates hadron-nucleus ( $A \geq 4$ ) interactions from a few MeV up to  $\approx 5$  GeV. These reactions show the characteristic threshold behaviour of meson production and in the program it is assumed that they are the superposition of three basic processes:

- a) inelastic collision of the projectile hadron (allowed particles are:  $\bar{p}, p, \bar{n}, n, \pi^0, \pi^+, \pi^-, k^+, k^-, \bar{k}^0, k^0, \bar{\Lambda}^0, \Lambda^0, \Sigma^-, \Sigma^+$ ) with a target nucleon in the nucleus; this interaction is calculated with HADRIN taking into account that now the nucleon has a Fermi momentum;
- b) induced intranuclear cascade with resulting proton and neutron emission;
- c) nuclear evaporation and deexcitation from residual nucleus. At the output the total energy available for these processes is given as excitation energy.

The mean excitation and cascade energies and the average multiplicities of cascade particles are parametrized, according to experimental distribution, as a function of energy, interacting hadron and target nucleus. In each event their values are sampled from a gaussian distribution: if they fall in the permitted kinematical region, energies and types of cascade nucleons are calculated and the remaining energy is

assigned to the incoming particle.

For hadron-nucleon interactions all relevant kinematic variables are Lorentz-transformed into the target nucleon rest-system. If interaction kinetic energy is then greater than the total available collision kinetic energy, a new Fermi momentum is sampled, otherwise an event is generated with HADRIN. Final state particles kinematical variables are transformed back into laboratory system; reaction and sampled event energies are again compared: if their difference is negative, energy is not conserved and generation has to be started once more with a new Fermi momentum sampling or if it is, on the contrary, positive, particle momenta and energies are corrected to reach conservation.

The user has to change all the internal weight tables used in HADRIN with a call to subroutines HADDEN and CHANWN that are slightly different from those used before because there is a suppression of some reactions to better reproduce experimental data. Events generation is performed by the instruction :

```
CALL NUCRIN (IT,CX,CY,CZ,ELAB,ANUC,ZNUC)
```

in which the projectile is specified by particle type (IT), total energy in GeV (ELAB), direction cosines (CX,CY,CZ) and the target nucleus by nucleon and proton numbers (ZNUC,ANUC), while all output variables are stored in the COMMON-block /FINUC/:

```
COMMON/FINUC/IRN,ITRN(60),CXRN(60),CYRN(60),CZRN(60),  
+ ELRN(60),PLRN(60),TV
```

where each Ith produced particles (whose number is IRN) has a code number ITRN(I), a total energy ELRN(I) (GeV), a momentum PLRN(I) (GeV/c), direction cosines CXR(I), CYR(I), CZR(I) and TV is the excitation energy.



#### 4. THE MONTE CARLO PROGRAM

To construct the new simulation program we first created a new hadronic library containing HADRIN and NUCRIN. Because HADRIN initialisation is different when used alone or inside NUCRIN, we created a library with two HADRIN copies so as not to occupy common memory areas. To link GEANT3 and this new library we modified GHEISH, one of the GHEISHA interface routines, in which, the particular hadronic interaction to be simulated is specified by the setting of the flag INT: none (INT=0), elastic incoherent (1), inelastic (2), elastic coherent (3) and nuclear fission (4).

The call inside this routine of HADRIN or NUCRIN, depending whether there is an hadronic interaction on hydrogen or heavier nuclei, and the initialisation of input variables used in the selected program are simply done with a "by-pass" of GHEISHA routines in the case:

- INT = 2
- primary hadron energy less than 5 GeV

(in all the other cases GHEISHA is still used).

Generated particles characteristics, stored in the COMMON blocks /FINLSP/ and /FINUC/ added at the beginning of GHEISH, are then copied back in GEANT3 stack and the program resumes its normal flow. In the user defined GEANT3 subroutine UGINIT, before events generation, there is a call to the four routines (two for each program) necessary for HADRIN and NUCRIN initialization.

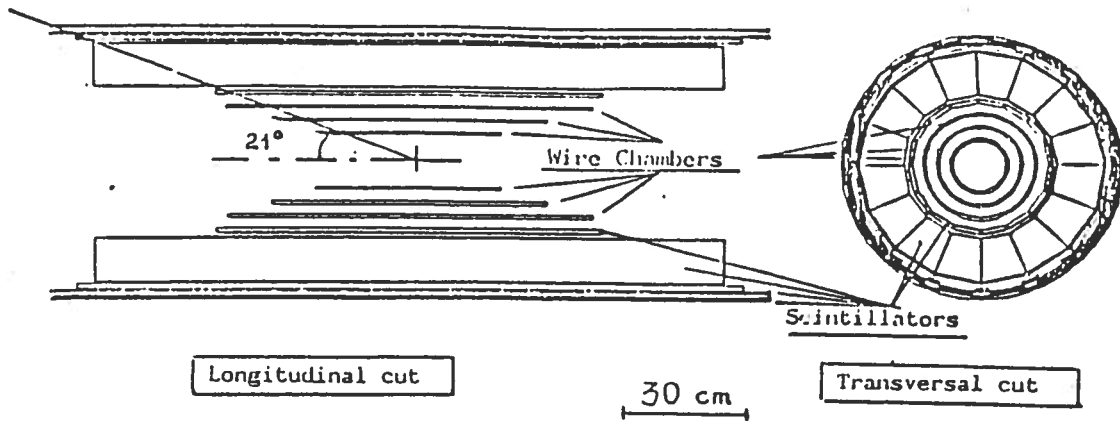
For the particular case that will be discussed in the next chapter, two more interface routines have been modified: CSDATA, because p-p interaction probability values are, below 1 GeV/c, lower than the experimental ones and p-n cross section is assumed to be equal to p-p and GHESIG, in which hadron-nucleus cross section is calculated with a general formula valid only for momenta > 2 GeV/c. Because in the following example only  $p$ ,  $n$ ,  $\pi^+$ ,  $\pi^-$  reactions on plastic scintillators are considered, their cross sections below 1 GeV/c are calculated starting from experimental data on carbon and proton.

## 5. SIMULATION OF EVENTS IN OUR EXPERIMENTAL APPARATUS

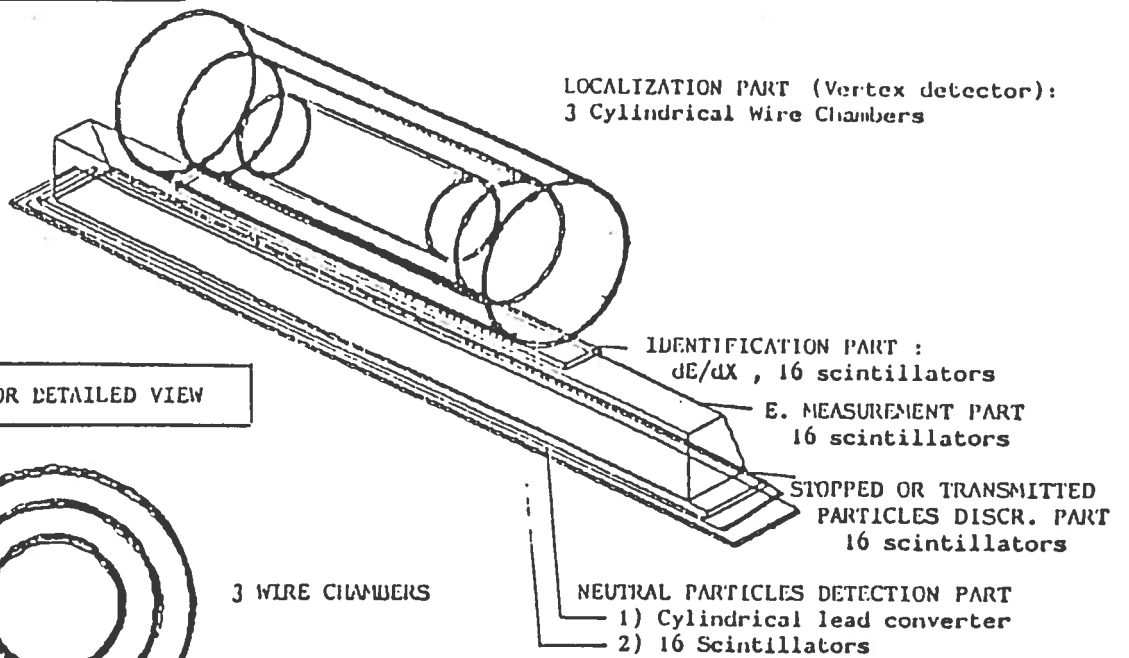
A schematic view and the main characteristics of our experimental set-up, a large solid angle detector covering an angular region of  $0.94 \cdot 4\pi$ , are shown in figure 4 and table III (ref.8). The target, located at the detector center, is exposed to a tagged photon beam, produced by in-flight positron annihilation, whose energy ranges from 150 to 550 MeV with a typical flux of  $\approx 10^4 \gamma/s$  (ref.9). The system of three cathodic concentric cylindrical wire chambers surrounding the target is a vertex detector able to measure accurately charged particles angles to better than 10 mrad. Particles type and energy are determined with 3 concentric hexadecaedric plastic scintillator layers (all made of 16 sections): the first and the second (1cm. and 10 cm thick) identify and measure the energy of stopped charged particles while the third (1cm.) separates stopped and transmitted particles. To detect neutral particles with a reasonable efficiency a cylindrical lead converter (5 mm) and another scintillator layer (5 mm.) have been added and in the future we hope to add a cylindrical calorimeter ( $\approx 10$  radiation lengths) to cover higher energy ranges.

Monochromatic protons, photoproduced from a target exposed to a bremsstrahlung beam and detected in the focal plane of the ALS "700" magnetic spectrometer (ref. 10), were used to calibrate and test all the scintillator layers. One of these preliminary measures has also been used to check the validity of our simulation program; the results of this comparison are shown in figures 5 and 6 in which full line histograms represent the experimental spectrum given by one of the "E" scintillators (10 cm thick) to protons with mean momentum of 560 and 700 MeV/c that are, respectively, completely stopped and transmitted by this detector, and theoretical points, convoluted with experimental resolution, are calculated without taking into account the excitation energy. We can see that the long tails outside the ionization energy loss peaks, due to hadronic interactions, are well simulated both in amplitude and in form; the program thus shows a good reproduction of cross sections and branching ratios and it can therefore be used for our analysis.

One of its most important applications is the evaluation of experimental pion/proton separation, necessary for a good event reconstruction and to be able to distinguish photoproduction from photodisintegration. Monte Carlo results, obtained taking into account also direction information given by wire chambers and experimental scintillator resolution, are



PERSPECTIVE VIEW



ONE SECTOR DETAILED VIEW

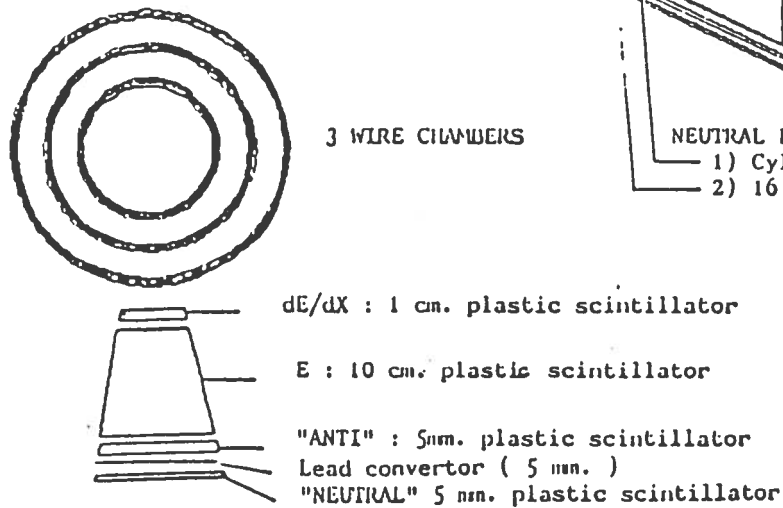


Fig. 4. Schematic view of the detector

Table III

Principal characteristics of the detector

ANGULAR ACCEPTANCE

Production angle :  $21^\circ < \theta < 159^\circ$   
 Azimutal angle :  $0^\circ < \varphi < 360^\circ$       94% of  $4\pi$

CHARGED PARTICLES DETECTION THRESHOLD ( 1 g. cm<sup>-2</sup> target)

Pions	$T_S = 12 \text{ MeV}$	$p_S = 60 \text{ MeV/c}$
Protons	$T_S = 23 \text{ MeV}$	$p_S = 220 \text{ MeV/c}$

MAXIMUM ENERGY & IMPULSION OF STOPPED PARTICLES

		In the plastics	In the lead
PIONS	$\theta = 90^\circ$	$T = 57 \text{ MeV}$ $p = 138 \text{ MeV/c}$	$T = 65 \text{ MeV}$ $p = 150 \text{ MeV/c}$
	$\theta = 21^\circ$	$T = 120 \text{ MeV}$ $p = 219 \text{ MeV/c}$	$T = 129 \text{ MeV}$ $p = 229 \text{ MeV/c}$
PROTONS	$\theta = 90^\circ$	$T = 125 \text{ MeV}$ $p = 500 \text{ MeV/c}$	$T = 140 \text{ MeV}$ $p = 531 \text{ MeV/c}$
	$\theta = 21^\circ$	$T = 225 \text{ MeV}$ $p = 688 \text{ MeV/c}$	$T = 255 \text{ MeV}$ $p = 737 \text{ MeV/c}$

NEUTRAL PARTICLES DETECTION EFFICIENCY

	PHOTONS ( 50 MeV )	$\pi^0$ ( By one at least )	NEUTRONS
$\theta = 90^\circ$	$\epsilon = 46 \%$	71 %	10 %
$\theta = 21^\circ$	$\epsilon = 82 \%$	97 %	30 %

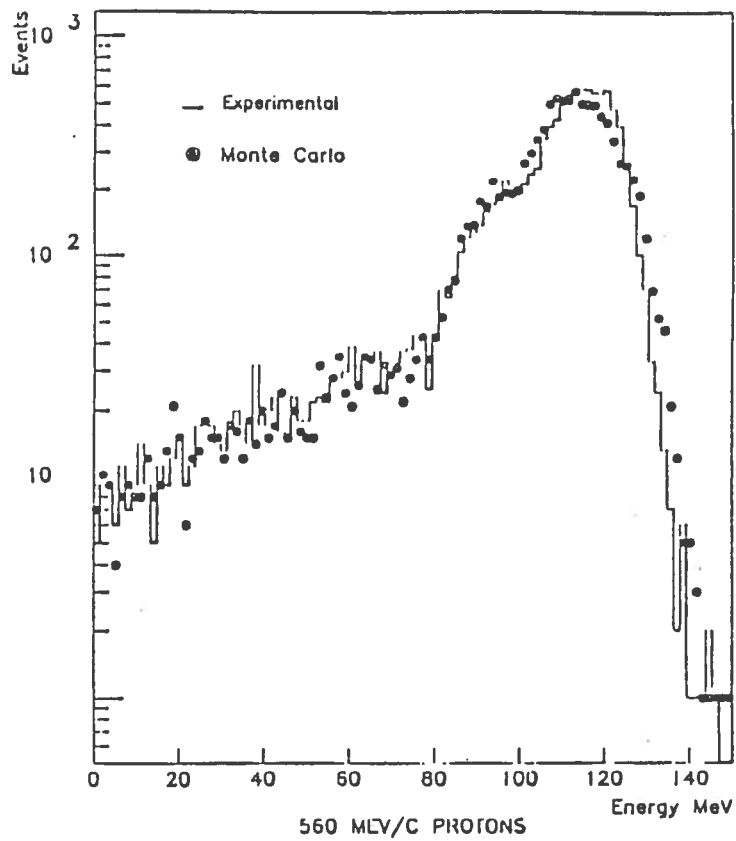


Fig. 5. The experimental response to 560 MeV/c protons given by a 10 cm thick plastic scintillator is compared with Monte Carlo results.

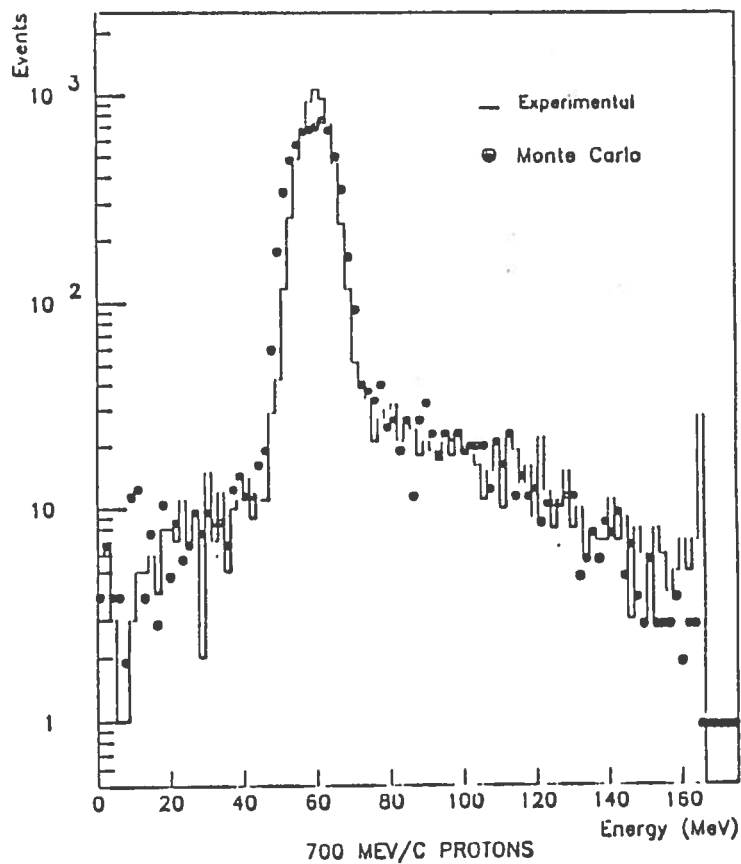


Fig. 6. Same as in Fig. 5 but with proton momentum = 700 MeV/c.

plotted in the 2-dimensional histogram of Fig.7 that reproduces coincidence measurements between "E" and "DEDX" scintillators.

This simulation shows a good separation in all the energy range that can be covered by this detector also if attention must be paid to hadronic pion interactions, mainly responsible for the events spread outside ionization energy loss regions. If a small branching ratio photonucleon emission process is to be studied (for instance the  $(\gamma,pp)$  reaction) they can give a not negligible background.

## 6. CONCLUSIONS

In this note we described the Monte Carlo program we used to simulate our detector. It was obtained integrating GEANT3 package with the codes HADRIN and NUCRIN to correctly reproduce hadronic interactions below a few GeV. Comparisons with experimental data have shown a good agreement and our program is therefore suitable to perform analysis also in the low and intermediate energy range.

We used GEANT3 version 9.11, however adopted solutions can be eventually applied, with slight modifications, also to the more recent packages.

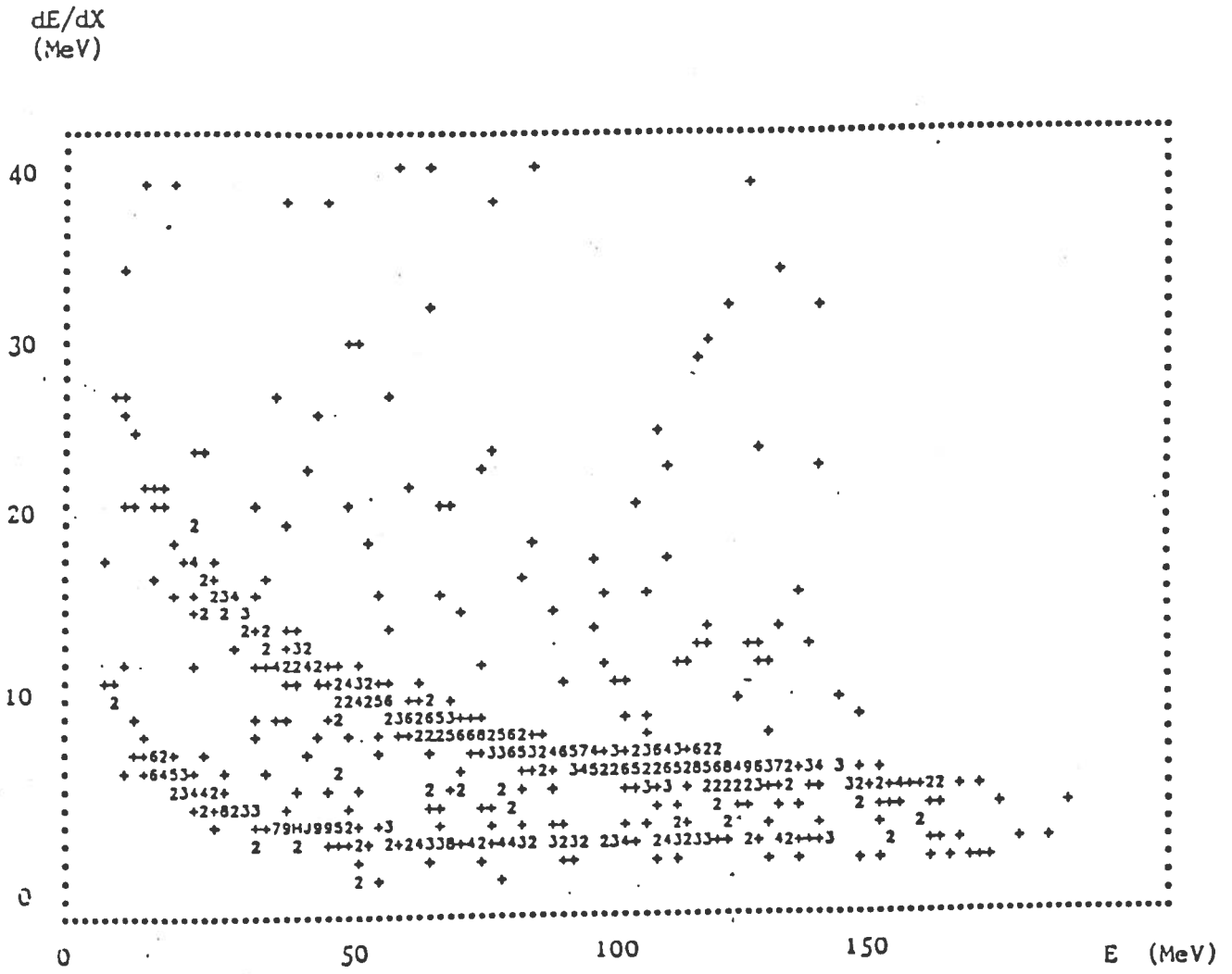


Fig. 7. Simulation of a "E"- "DEDX" coincidence measurement

## REFERENCES

- 1 - R. Brun, GEANT3 Users Guide, CERN DD/EE/84-1 (1985) (unpublished).
- 2 - H.C. Fesenfeldt, "Simulation of Hadronic Showers", PITHA rep., RWTH Aachen (1984) (unpublished).
- 3 - "Experimental Nuclear Physics" vol. II, edited by E. Segrè, (Wiley & Sons, New York, 1953) p. 165-189.
- 4 - K. Hanssger and J. Ranft, Comp. Phys. Comm. 39, 37 (1986).
- 5 - K. Hanssger and S. Ritter, Comp. Phys. Comm. 31, 411 (1984).
- 6 - U. Amaldi, Ann. Rev. Nucl. Sci. 26, 385 (1976).
- 7 - K. Hanssger and J. Ranft, Comp. Phys. Comm. 39, 53 (1986).
- 8 - G. Audit et al., in "Perspectives in Nuclear Physics at Intermediate Energies", edited by S. Boffi, C. Ciofi degli Atti and M.M. Giannini (World Scientific, Singapore, 1988) (to be published)
- 9 - P.E. Argan et al., Nucl. Instr. Meth. A228, 20 (1982).
- 10 - P.E. Argan et al., Nucl. Phys. A237, 447 (1975).