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SPARK CHAMBER NEUTRON AND PROTON SPECTROMETER: FIRST REPORT ON PERFORMANCES*

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ABSTRACT

An instrument has been built to measure neutron and proton spectra in the energy range between about 30 and 300 MeV to be used in fields as low as about 0.1 particle cm^{-2} s^{-1}. The software and hardware of the unit have been described elsewhere.[1,2]

We report on the checks and improvements of some of the unfolding computer programs, on the measurements performed in a proton beam and in a neutron beam at the 184-Inch Synchrocyclotron, and on some measurements of stray proton spectra behind the shielding of the accelerator. We discuss finally the improvements that are needed for a full use of the potentialities of the instrument.

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1. THE PROGRAM FOR UNFOLDING THE PROTON SPECTRUM

The sensitive part of the detector is made of a sandwich of 12 multiwire spark chambers (50×50 cm^2 dimensions), 15 plastic scintillators and 13 converter-absorbers of polyethylene 2.54 cm or 0.635 cm thick (see Fig. 1).

In the proton measuring mode, one event is a coincidence among the first three scintillators plus an anticoincidence with the last one, while in the neutron measuring mode it is a coincidence between at least two internal scintillators plus an anticoincidence with the first and last scintillators. Such an event, i.e., a proton entering the detector in the first case or a proton produced inside the detector by an incoming neutron in the second case, triggers the high voltage to the spark chambers. The coordinates of the sparks in the spark chambers are recorded on a magnetic tape via a magnetostrictive readout system.

The computer program PTAPE reads from the tape the coordinates of the sparks for every event, calculates the length and the direction of the proton track, and, calculates the energy of the proton for a given thickness of absorber. It then plots a graph and punches cards of the number of protons versus energy and a table of angular direction versus energy.

In the neutron measuring mode from single scattered protons, the proton spectrum on punched cards, together with a matrix kernel and correction data calculated through a Monte Carlo program (DEER), provide the input for the program (LOUHI) which unfolds the neutron spectrum.

For the checking the precision of the program PTAPE we have modified its input such as to accept punched cards, and we have fed it with preconstructed sample events on punched cards.

For the use of the instrument as a neutron spectrometer from double scattering events, a modification of PTAPE has been written (called ASINO) which sorts from the magnetic tape only those events where the incoming neutron undergoes two consecutive proton scatterings inside the detector. It calculates the scattering coordinates, track direction and energy of the two protons, and, from these data, calculates and plots the neutron spectrum and angular distribution.

2. MEASUREMENTS IN A PROTON BEAM

A beam of 300 MeV protons from the 184-Inch Synchrocyclotron was extracted, collimated, and directed toward the front face of the spectrometer. It was used for timing the triggering scintillators. Then a block of 5.3 cm of copper was introduced in the beam. This reduces the energy of the protons to about 163 MeV. 1000 odd events were recorded under these conditions. Then the beam attenuator was replaced with one of 4.3 cm thickness, which reduced the energy of the protons to about 193 MeV and another 1000 events were recorded. The results of these measurements as provided by PTAPE are shown in Fig. 2.

The width of the proton energy intervals for plotting the spectrum can be set to any value in the PTAPE program--it depends, of course, on the thickness of the absorbers and on the angular distribution of the protons. In Fig. 2 it is 8 MeV.

The figure shows the energy peaks at about 157 and 182 MeV. The small discrepancy with the calculated values can be because the exact energy of the primary beam was not measured. If it was 295 MeV instead of the assumed 300 MeV, the calculated and measured values coincide. (N.B. The calculation of the proton energy after crossing the copper attenuator was done using the formula

$$E_1 = \left[E_2^{1.64} - \frac{S}{7.27 \times 10^{-4}} \right]^{1/1.64}$$

where S is the copper thickness in cm, E_2 and E_1 are the proton energy in MeV before and after the attenuator respectively. This formula has been derived from an exponential range-energy relationship, i.e., of the type $R=K\,E^a$).

The results also show that the events were produced by proton whose tracks cross the spectrometer normally, i.e., that the spread of the beam at the attenuator was negligible.

Figure 2 confirms that the resolution that can be achieved in the spectrometer is dictated only by the thickness of the absorbers.

3. STRAY PROTON SPECTRA MEASUREMENTS

The spectrometer was positioned behind the shielding of the 184-Inch Synchrocyclotron, inside the accelerator building. The triggering logic was set as for triggering only on charged particles and spectra were taken for different experimental set ups at the accelerator. When we use this triggering logic there is still a probability of triggering on neutrons; this probability is the probability that the neutron undergoes a (n,p) reaction in the first scintillator. In Fig. 3 we plot this probability as a function of the n energy for a plastic scintillator 0.32 cm thick. The discriminators of the triggering scintillators have only an upper threshold which was set for β rays from a Ru^{106} source. So we trigger on all the charged particles which have a dE/dx higher than ~ 1.5 MeV cm^2g^{-1} in plastic scintillators. If a proton is scattered in the first scintillator, it must have an energy of at least 50 MeV to be able to produce a pulse in the next two scintillators and generate a false triggering event. It can be produced only by neutrons of energy higher than 50 MeV. At this energy the probability of scattering a proton in the first scintillator is ~ 2×10^{-3}. Then the number of spurious events produced by neutrons to protons is lower than about 500:1 :in such a field one can expect to have some 30% of events produced by neutrons.

The triple coincidence rate during the measurements was about 10 events per second. This rate for the given dimensions of the scintillators (50×50 cm^2) is produced by a field of 4×10^{-3} particles $cm^{-2}s^{-1}$. A BF_3 moderated neutron counter, which is sensitive to neutrons of energy between about 100 keV and 5 MeV, was set beside the spectrometer and indicated a field of about 5 n $cm^{-2}s^{-1}$. Assuming a neutron spectrum of the 1/E type, one can infer that there were not more than about 0.5 n $cm^{-2}s^{-1}$ of energy higher than 50 MeV. The ratio of neutrons to protons was, then, about 100:1. We can conclude that the number of spurious events in the spectra was very small.

Figure 4 shows a proton spectrum recorded when a 750 MeV p beam, extracted from the 184-Inch Synchrocyclotron, was stopped in a Cu target located inside an experimental cave. The spectrometer was located at about 90° from the beam direction, some 20 m from the main target; the thickness of the concrete wall of the cave in the direction of the spectrometer was about 4 m. The angular distribution of the detected protons indicates the target as the

main source.

Figure 5 shows a spectrum taken from the same position. This time the extracted 750 MeV p beam was mainly stopped in a concrete beam stopper at the end of the cave; the experimental targets were absorbing only a small fraction of the beam.

The slopes of the curves of Figs. 4 and 5 are about the same. The curves seem to fit quite well an equation of the type $N = K_1 e^{-K_2 E}$ where N is the number of protons E is their energy, and K_1, K_2 are constants.

Figure 6 shows a spectrum taken when the 670 MeV proton beam was stopped in a target inside the accelerator. In this measurement the secondary particles had to cross the iron of the magnet yoke and the external 3 m concrete shielding before reaching the spectrometer.

Several authors have performed Monte Carlo calculations of charged particle spectra produced by high energy proton beams and transmitted through different materials (see, for instance Refs. 3,4). In particular, J. Routti has kindly performed the calculation of the transport of the cascade in an Al block using the computer program TRANKA.[5]

The shape of the spectra we have measured seems to fit the theoretical calculations. However, our experimental geometrical conditions were not precisely defined. We are planning to perform other measurements under more controlled experimental conditions, such that comparisons with calculated results can be unambiguously made. In addition, the absolute proton and neutron fluences have to be evaluated.

We are also planning to improve the spectrometer design. The rate of event recording is limited to about 1 event per second by the tape recorder; the gas and high voltage supplies for the spark chambers and the triggering scintillators make the apparatus rather heavy and cumbersome.

In view of its possible application for measuring spectra at different altitudes in airplanes, we are planning to replace the multiwire spark chambers with sealed multiwire proportional chambers which will eliminate the necessity of triggering scintillators.

We want to thank Dr. Ralph H. Thomas for his continuous encouragement and his help in measuring the proton spectra at the 184-Inch Synchrocyclotron.

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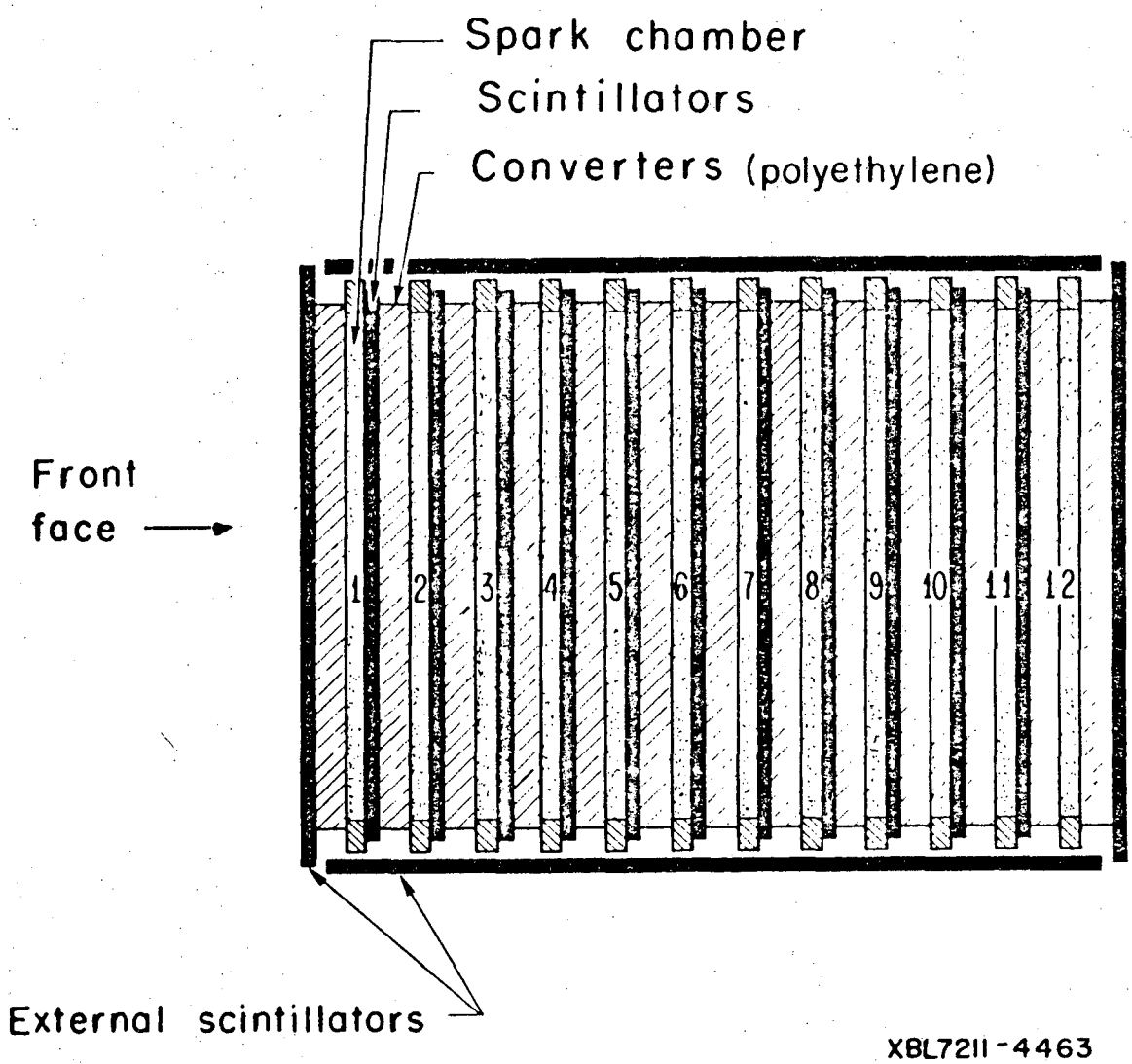

Figure 1. A schematic view of the sensitive part of the spectrometers.

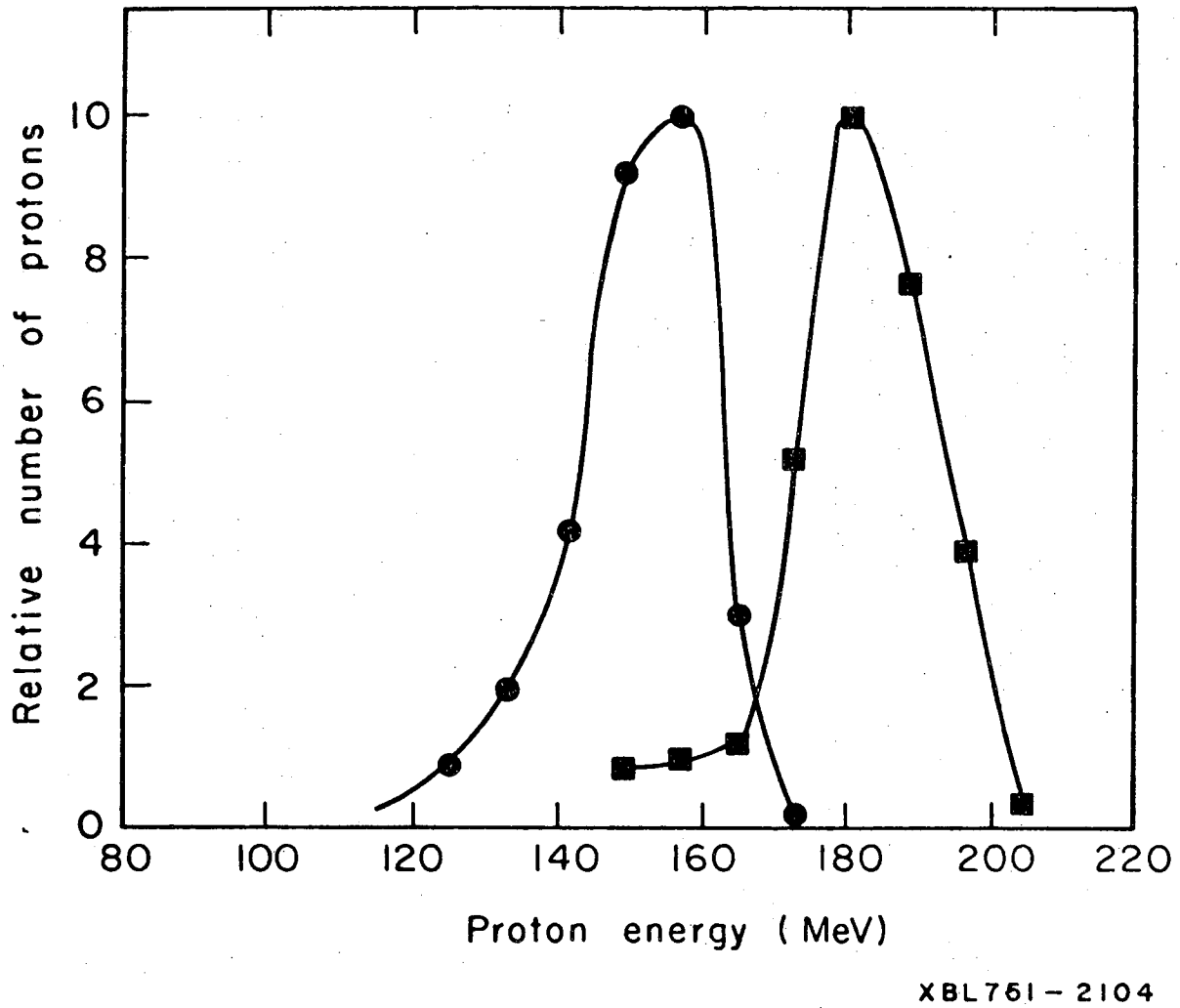

Figure 2. Spectrum of proton measured in the 300 MeV proton beam of the 184-Inch Synchrocyclotron, attenuated in 5.3 cm (peak at left) and 4.3 cm of copper (peak at right).

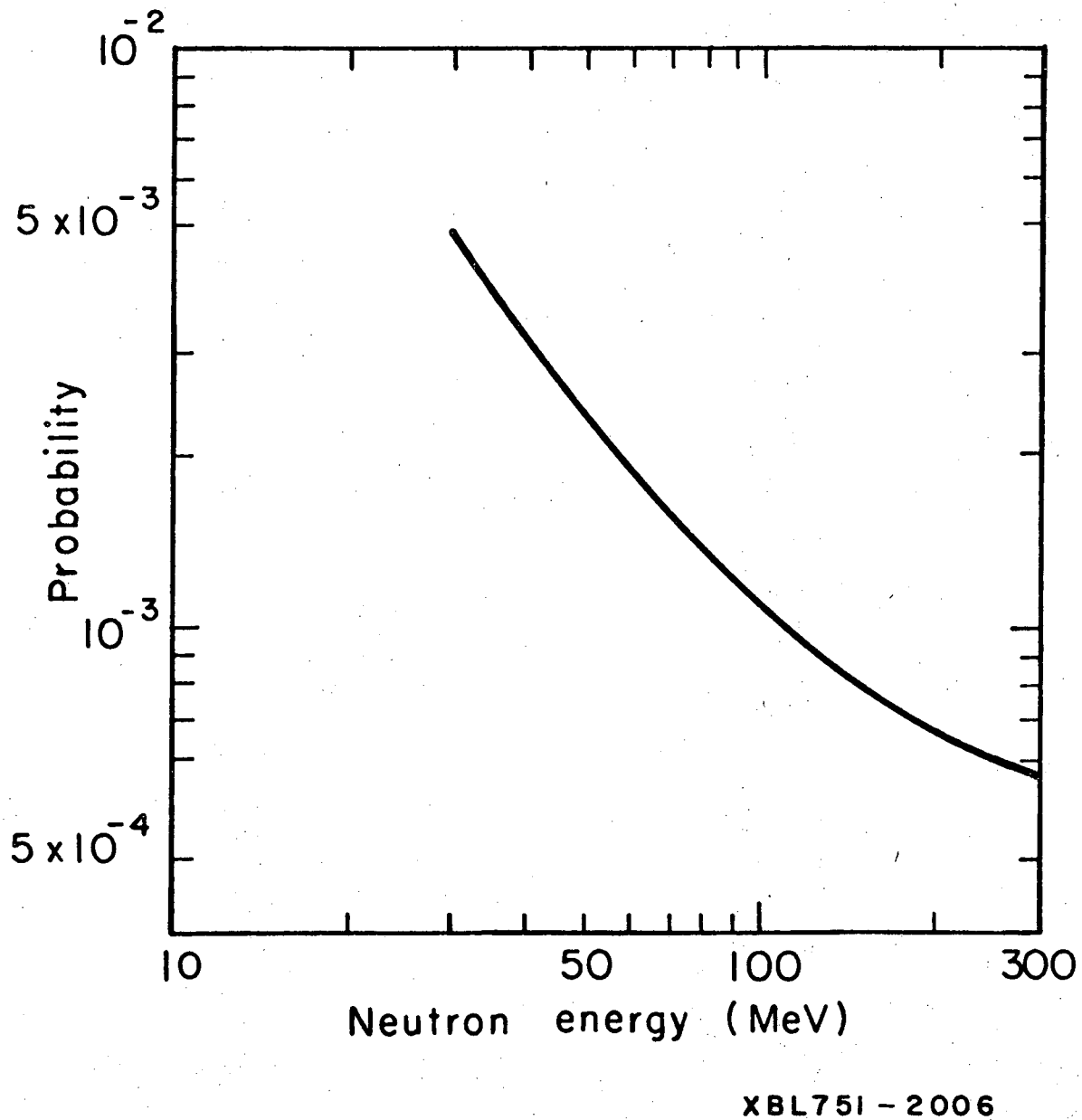

Figure 3. The probability that a neutron produces a recoil proton in the first triggering scintillator as a function of the neutron energy.

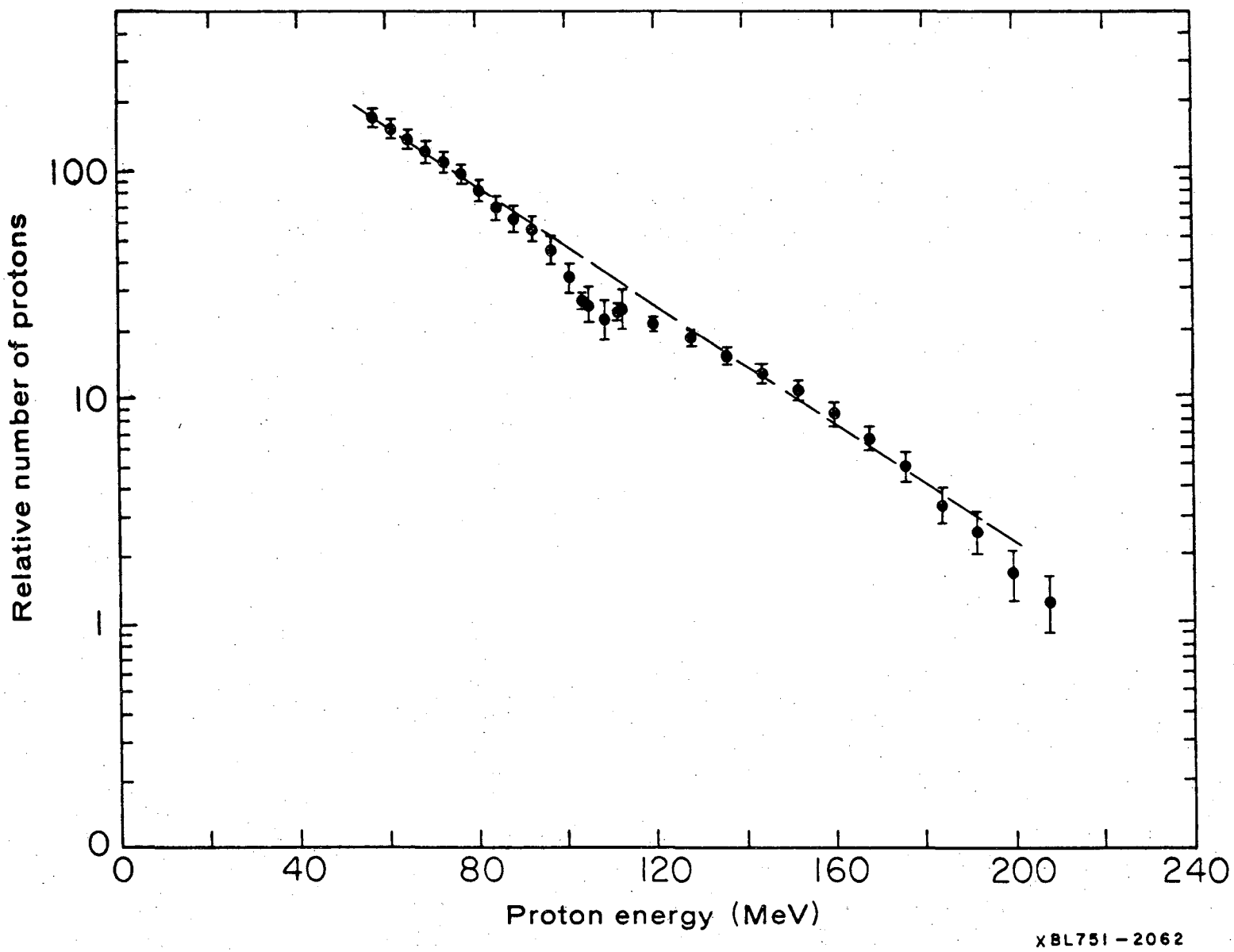

Figure 4. Proton spectrum measured in the building of the 184-Inch Synchrocyclotron when a 750 MeV p beam was stopped in a Cu target inside a shielded experimental cave (proton cave).

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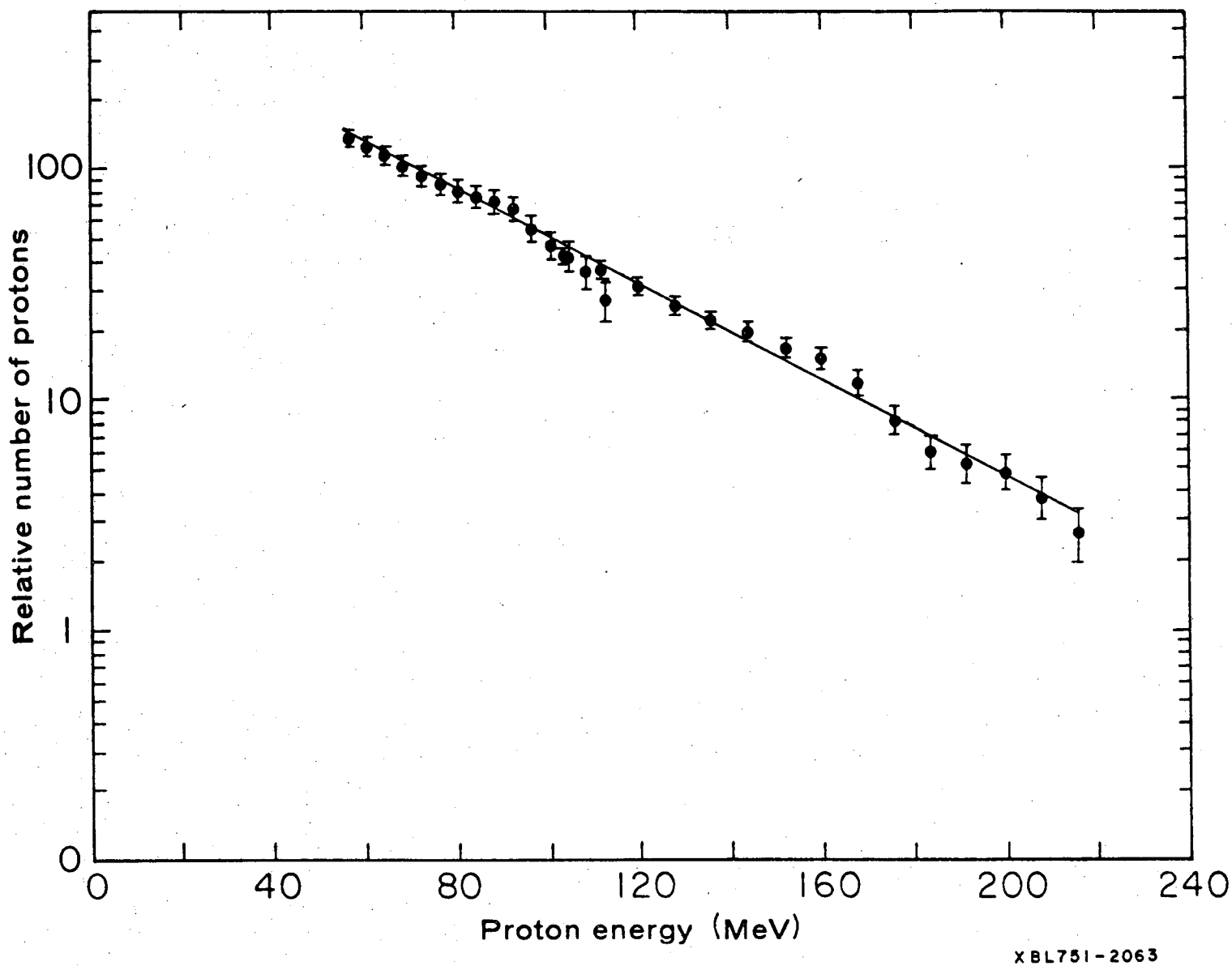

Figure 5. Proton spectrum measured in the building of the 184-Inch Synchrocyclotron when a 750 MeV proton beam was stopped in a concrete beam stopper inside a shielded experimental cave (proton cave).

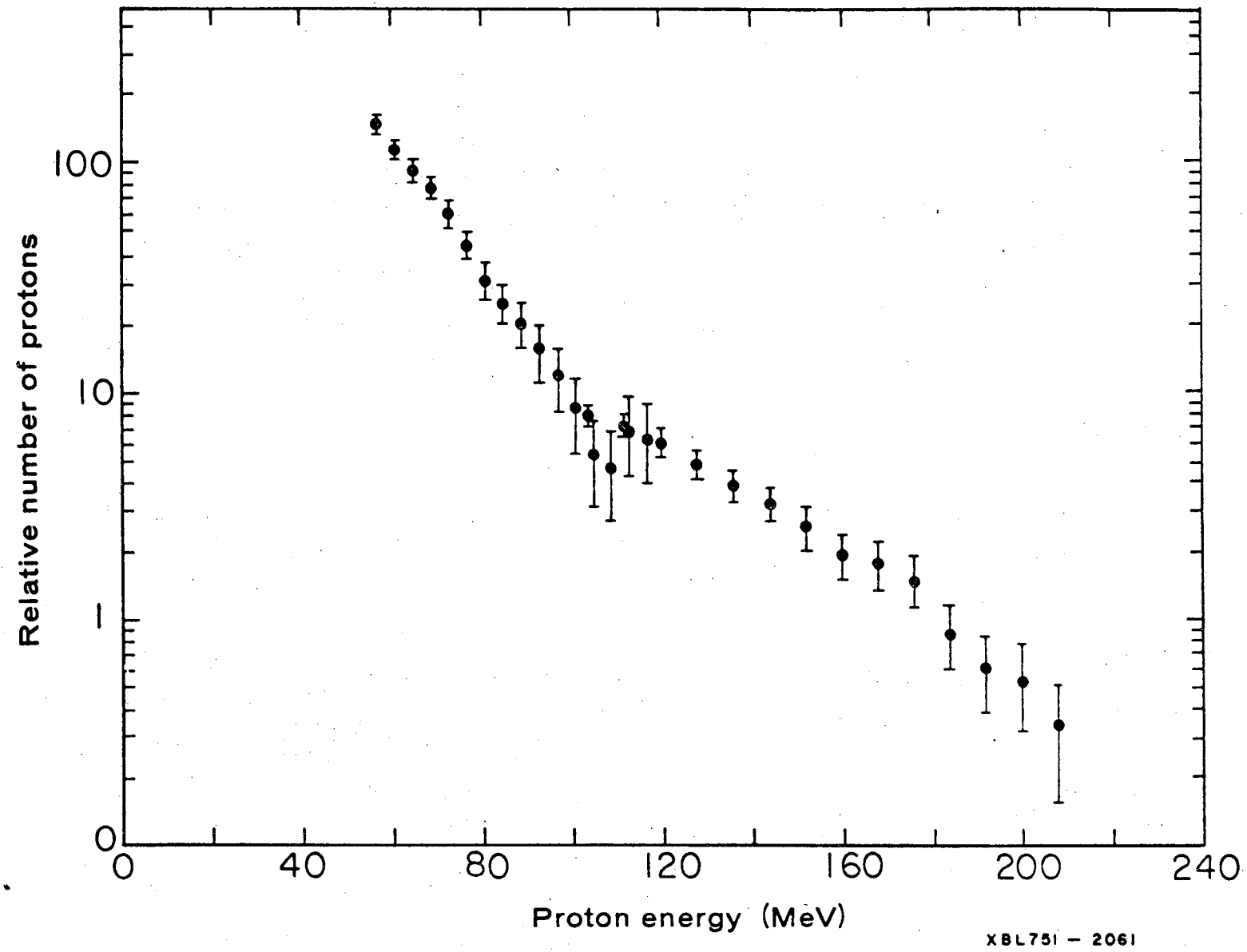

Figure 6. Proton spectrum measured behind the shields of the 184-Inch Synchrocyclotron when the 670 MeV p beam was hitting a target inside the accelerator.

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