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SOME PRELIMINARY INVESTIGATIONS ON THE CONTRIBUTION OF MUONS TO THE STRAY RADIATION LEVEL AROUND THE CERN 28 GeV PROTON SYNCHROTRON

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Abstract

Below a few GeV the predominant radiation in the environment of accelerator installations is stray neutrons. Muons may however become dominant if pions and kaons produced by the interacting primary beam are allowed to decay in the course of free flight and the resulting muons in forward direction are not sufficiently shielded.

Measurements with a counter telescope allowing for the determination of their angular distribution behind the shield around the beam direction are reported. The attenuation length for muon spectra from the decay of pions of a few GeV in several materials was determined and is compared with theoretical values. The measurements show in addition the contribution to stray radiation levels by other components penetrating the main shield of the accelerator. Their relative importance at different distances and their environmental impact are discussed.

Introduction

Radiation protection measurements around multi-GeV proton accelerators are difficult due to the largely unknown mixture of stray radiation outside the shielding. This is caused by the interactions of primary protons with target and shielding materials giving rise to a variety of secondary radiations covering a wide energy

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range. The predominant penetrating component of the dose measured is generally neutrons.

The contribution of muons, however, may become important if pions and kaons produced in the interaction of the primary beam are allowed to decay in the course of free flight into mu-mesons. A certain attenuation of the latter component projected in the forward direction requires more shielding than is needed for the parent pions, since the muons -- up to the energy range which is important for our problem -- only interact electromagnetically whereas the hadrons in addition undergo nuclear interactions.

The attenuation of hadrons is predominantly exponential in the shielding and may be described by a single parameter, i.e. the attenuation length λ which is about 130 g cm^{-2} in iron shielding for proton beams of 10-300 GeV.

Although the attenuation curves for muons (calculated and measured) turn out not to be simply exponential, they still may be characterized over certain depths by one single parameter and the apparent attenuation lengths for muons for primary proton energies of 25 GeV range between 430 and 900 g cm^{-2} [1-3]. These values are influenced by the choice of the production formulae of pions, their decay path (length and angle) and the resulting muon spectrum but seem less influenced by the shielding materials used in the calculations.

Experimental Equipment

A counter telescope was constructed to detect muons resulting from the decay of pions and kaons in the forward direction downstream of targets and after penetrating the shielding wall of the accelerator enclosure.

Three scintillation counters in triple coincidence of 5 cm width, 20 cm height and 2 cm thickness are mounted on a supporting bar at a distance of 75 cm from each other. The supporting bar pivots around a central axis in the horizontal plane and can be moved in the vertical plane as well. The pulses observed from the telescope are counted and are stored according to their height in a 256 multi-channel analyser with a 100 MHz ADC. All measurements are made with reference to a two-fold coincidence monitor counter left in a fixed position in the radiation field during the measurements. This is done in order to take into account intensity variations of the accelerator.

Results

The equipment was tested first in a series of measurements performed at an angle of 6^{o} with respect to an internal target at a distance of 45 m. The total shielding thickness between target and detector amounted to only 3000 g cm^{-2}. A typical recorded spectrum is shown in Fig. 1. This consists of a peak at low channel numbers corresponding to a small stopping power or minimum ionizing particles and a long tail with higher stopping power.

When additional shielding material (lead, iron) is placed in front of the first counter, a second peak at higher channel numbers appears and the first peak decreases (Fig. 2). The conclusion of this effect is as follows: the radiation penetrating the shielding wall is muons "contaminated" with hadrons. Different kinds of particles in the GeV range however have roughly equal stopping power, about 2.2 MeV g^{-1} cm^{2}, in a scintillator and will thus be found peaked around the same channel numbers. By introducing shielding the hadrons produce forward-peaked secondaries of lower energies that build up the second peak as these cause a higher energy loss in the detector.

By increasing the shielding thickness this second peak is found to be attenuated with a λ corresponding to hadrons, whereas the first peak decreases with an attenuation length which approaches a value expected for muons.

The apparent attenuation lengths for muons determined from this experiment were 379 g cm^{-2} for lead and 457 g cm^{-2} for iron.

A second series of experiments was performed using a test beam tuned to 19 GeV/c pions. The same build-up phenomenon was observed. Attenuation lengths for muons gave in this case values of 417 g cm^{-2} for lead and 491 g cm^{-2} for iron, in other words slightly higher than in the preceding experiment. From these measurements a superiority of lead of about 20% compared to iron was found for the attenuation of muons.

In a third series of measurements an attempt was made to detect muons behind a beam stop in an experimental hall. An extracted beam from the PS interacted with a target located 23 m upstream of the shielding (Fig. 3). Spectra were recorded in seven positions and all of these showed only one peak with no "tail" towards higher channel numbers. Figure 4 is shown as an example.

When the counter telescope was turned in the horizontal plane around its vertical axis, the maximum count-rate was observed when the instrument pointed in the direction of the target. The angular dependence of the muon intensity, for example for position 6 (Fig.3), is shown in Fig. 5. The angular response of the telescope for monodirectional radiation has the shape of a triangle and is also given in the figure. It was shown by calculations that the measured angular distribution is not distorted by this response function and thus corresponds to the actual one.

A more complicated intensity distribution of the muons, which could be decomposed into three peaks, is observed at for example position 2 (Fig. 6).

Figure 3 indicates the positions in which observations with the telescope were carried out. The arrows point in the direction of measured maximum muon intensities; their lengths have been drawn proportional to the height of the measured peaks. The extensions of these arrows pass through the target -- the main source of pions and subsequently muons -- or point to some weakness in the shielding, for example in the direction of reduced thickness of iron.

Comparisons of these measured muon intensities with dose measurements in the same places show that the contribution to the dose from directed muons may vary and could reach as much as half of the total value.

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Figure Captions

Fig. 1. Pulse height spectrum of events recorded with counter telescope behind 3000 g cm^{-3} shielding material at 6^{o} from an internal target.

Fig. 2. Same as Fig. 1, but with 5 cm of lead in front of the first scintillator.

Fig. 3. Mu-meson measurements in the west experimental area downstream of an external target behind an end-stop made out of iron and concrete shielding material. The length of the arrows corresponds to the muon intensity; they are pointing in the direction of the maximum.

Fig. 4. Pulse height spectrum of events from mu-mesons as measured in position 5 shown on Fig. 3.

Fig. 5. Angular distribution of mu-meson intensity in position 5 of Fig. 3. The angular response function of the counter telescope having the shape of a triangle is also shown in this figure.

Fig. 6. Angular distribution of mu-meson intensity as measured in position 2 of Fig. 3.

FIG. 1

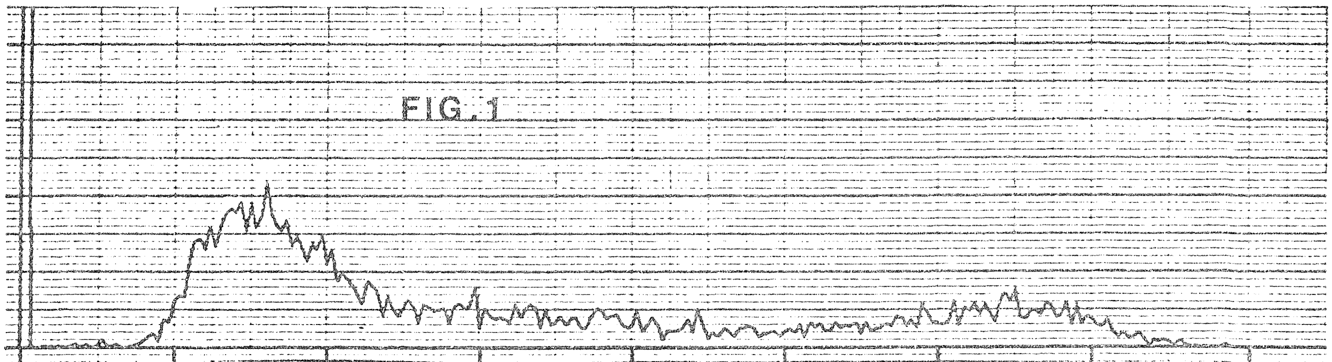


FIG. 2

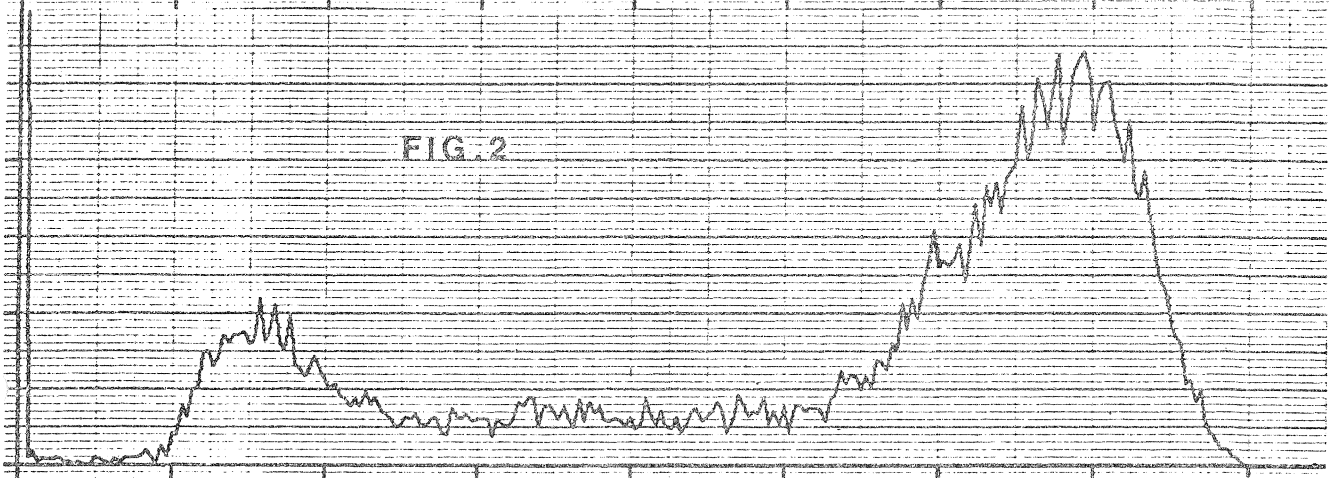


FIG. 4

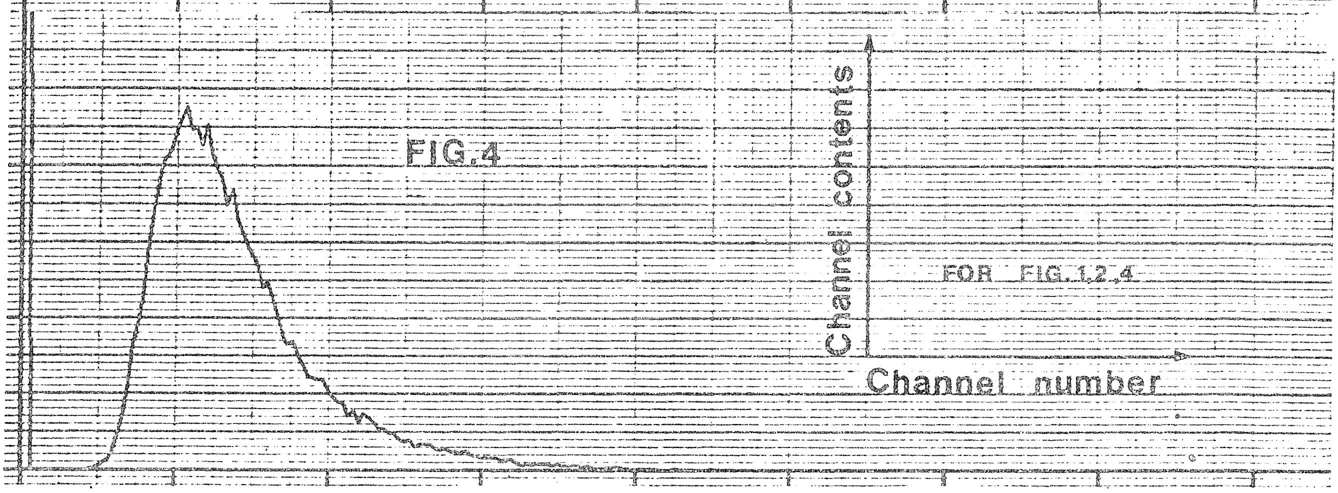
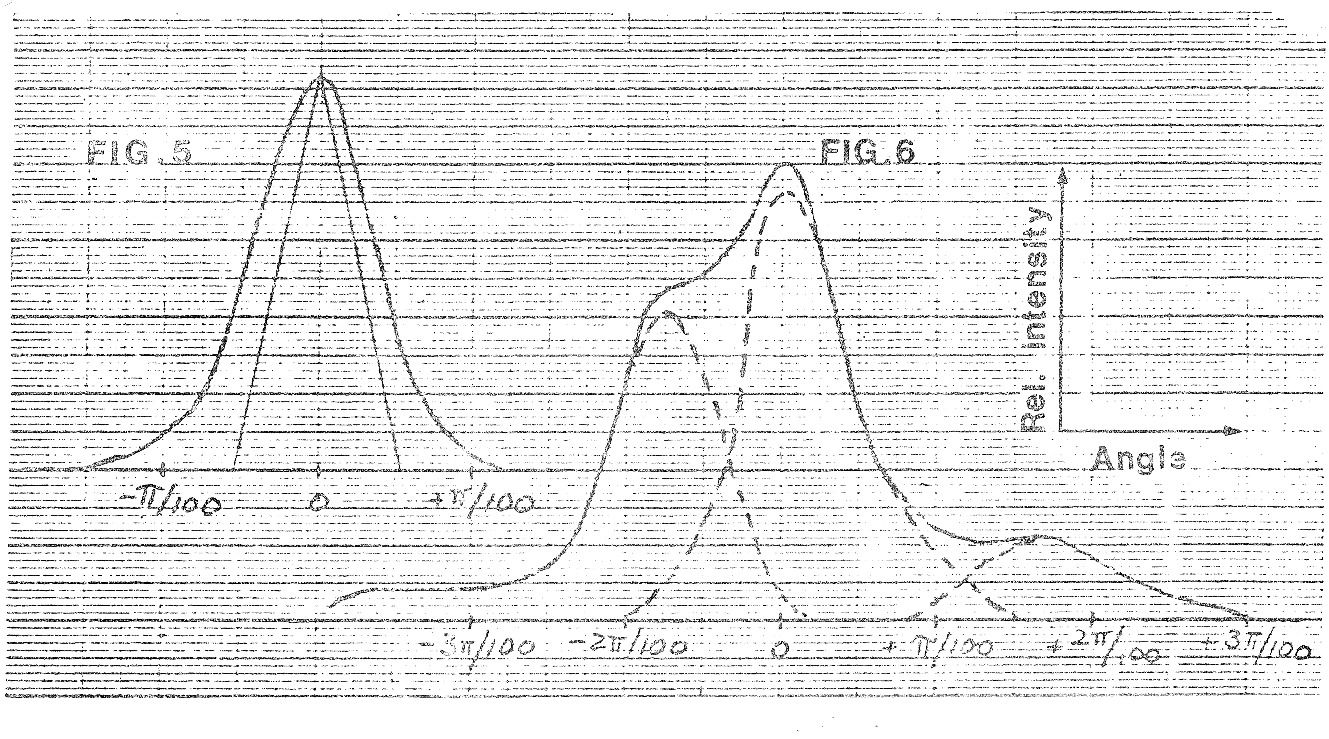


FIG. 5
FIG. 6



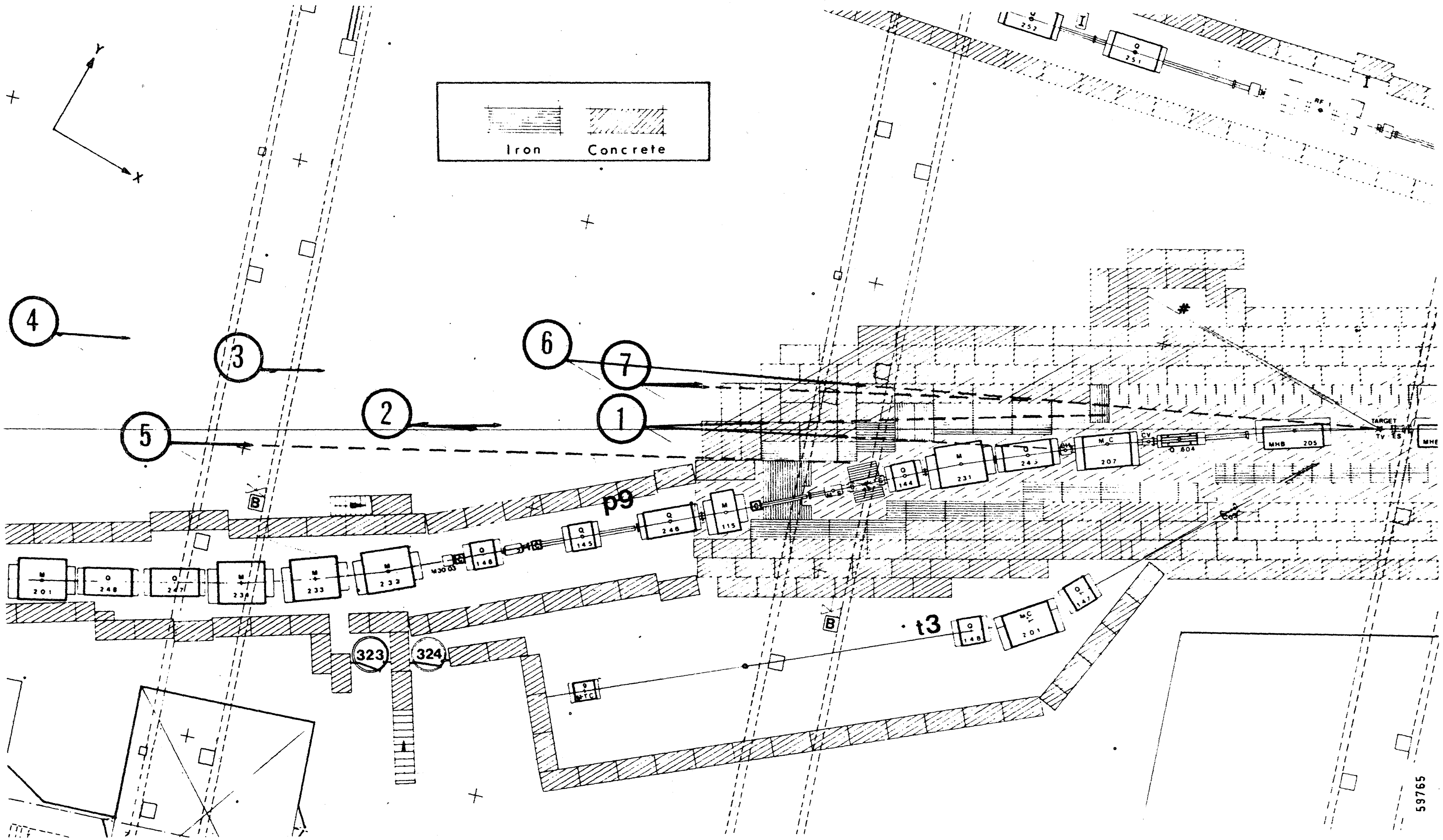


FIG. 3