Fermilab Proposal No. 436

Scientific Spokesman:

R.K. Adair
Physics Department
Yale University
New Haven, Connecticut 06520

FTS/Comm: 203 - 436-4771

Determination of the Possible Di-Muon Character of the Prompt Muon Flux

A Proposal to the Fermi National Accelerator Laboratory

R.K. Adair,* P.D. Bergey, D.M. Grannan, H. Kasha, R.G. Kellogg
and M.J. Lauterbach
Department of Physics, Yale University, New Haven, Connecticut 06520
and
L.B. Leipuner, R.C. Larsen and L.W. Smith
Brookhaven National Laboratory, Upton, New York 11973
and
R.J. Stefanski
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

---

*Spokesman

Determination of the Possible Di-Muon Character of the Prompt Muon Flux

A Proposal to the Fermi National Accelerator Laboratory

R.K. Adair,* P.D. Bergey, D.M. Grannan, H. Kasha, R.G. Kellogg
and M.J. Lauterbach
Department of Physics, Yale University, New Haven, Connecticut 06520
and
L.B. Leipuner, R.C. Larsen and L.W. Smith
Brookhaven National Laboratory, Upton, New York 11973
and
R.J. Stefanski
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

---

*Spokesman

SUMMARY

We propose to measure the di-muon flux produced by the interaction of 400 GeV protons with copper and compare this flux with the flux of single prompt muons in a manner which will determine whether the prompt muons flux is derived from muon pair production. We will measure the production of muon pairs such that each muon has a laboratory energy greater than 55 GeV and a production angle less than 35 milliradians (or transverse momentum less than 2.0 GeV/c). We demonstrate that we can determine the total cross section for the production of muon pairs, such that each muon has a laboratory energy greater than 55 GeV (or x greater than 0.1375), from our measurements. With the same apparatus, we will measure the total prompt muon flux such that the muon has an energy greater than 55 GeV. Using measurements made previously by us concerning the ratio of the prompt muon flux to the pion flux as a function of x for small p_t, together with measurements of the pion production spectrum made at various laboratories, we can correct for the energy dependence of the cross sections and then compare the total cross section for di-muon production with the total cross section for prompt muon production and then determine whether these cross sections are consistent with the view that they derive from the same source.

We will need about 75 hours of beam time using a set-up and equipment which are minor variations of the equipment used for Experiment 48. We will need one of the portacamps used in Ex. 48 moved about 16'. We will need 6 more duo-quad logic units from PREP. About 35 hours of the requested time will be required for data taking, about 40 for set-up and test time.

I. INTRODUCTION

The origin of the large prompt lepton flux produced in proton interactions is still obscure. Prompt leptons appear to be produced at intensities about an order of magnitude greater than might be accounted for by conventional sources and these leptons seem to be produced over a wide range of the Feynman variable x, p_t and s. Although the ratio of positive to negative leptons is nowhere very different from one -- and, indeed, may be exactly one -- it has not been established that the prompt leptons are produced in lepton-anti-lepton pairs (such as would be expected if the leptons are produced through electromagnetic processes) or if the leptons are produced singly as from the weak decays of short lived intermediate particles which may, or may not, be produced charge symmetrically (the decays of charmed particles represent a hypothetical origin which would have these properties). Although a number of measurements of di-lepton intensities have now been reported, these measurements do not cover so wide a range of the kinematically available configuration space as to allow a precise comparison of the intensities so measured with the measured prompt lepton intensities. However, Lederman(1) has pointed out that simple and plausible extrapolations and interpolations of this di-muon data seem to lead to prompt intensities, from this source, which are much smaller than the intensities of prompt single leptons which have been observed. It is the purpose of the experiment proposed here to conduct di-muon measurements over a large range of kinematic variables in conjunction with the measurements of prompt single muons and then determine as to whether the prompt muons have their origin in di-muon production.

The proposed experiment is a part of, or extension of, Experiment 48 which is now running in the proton-central beam line. The measurements which have been made in that experiment(2) constitute a basis for a definitive design for the di-muon measurements which we propose here. Indeed, exploratory measurements of di-muon fluxes have already been made in the course of Ex. 48, and these measurements encourage us to believe that the more complete measurements proposed here can be conducted with no great difficulty.

II. EXPERIMENTAL DESIGN

The diagram of Fig. 1 suggests the character of the experimental design inasmuch as it defines the position of the counters which make up the di-muon spectrometer. There are 14 2'x3' "B" counters in the "center pit," a pit dug into the ground about 400' from the target. The counters are housed in two portacamps there. Since each counter subtends about 5 milliradians, the array extends to 35 mr on each side of the proton beam line. The "A" counters are 9" wide by 18" long and are installed at the rear of the "proton-central" hall. Each A-counter is centered on a line from the effective target position to the center of a corresponding B-counter. The minimum energy required of a muon to penetrate the target and the steel shielding in the upstream part of the hall and reach the A-counters is about 25 GeV. The minimum energy required to reach the B-counters through the additional 200' of dirt besides the steel, is 55 GeV.

The experiment consists of two parts: (a) a measure of the prompt muon flux through the system and (b) a measure of the di-muon intensity detected by the elements of the spectrometer. We first discuss the di-muon measurements.

We can consider the counter arrays as making up a 14 channel muon pair spectrometer which measures the intensity of pairs for all possible channel-channel correlations. We have already made some measurements to test the feasibility of the technique. Figure 2 shows the coincidence correlations for the set of counters marked with asterisks in the diagram of Fig. 1. The measurements here, using only wide angle counters, represent pairs with large invariant masses ($M \gtrsim 3$ GeV) and small transverse momenta and pairs with small invariant masses and large transverse momenta ($p_t > 3$ GeV/c). The counting rates are high even for this set of events which we expect to give the lowest counting rates. All of the data shown in Fig. 2 was taken parasitically in about 4 hours of beam time. During this time measurements of accidentals were also made and the accidentals were shown to be small for the channels with the higher counting rates. All indications suggested that the accidental rate was not too important even for the least intensive correlations, but it was not possible to completely exclude the possibility that beam structure effects could induce anomalously high accidental rates which could not be detected within the constraints of the parasitic run.

Since the object of the measurement is to compare the rates of di-muon production with the rates of production of single prompt muons, it will be necessary to measure the prompt muon intensities in the same geometry. Such correlated measurements will largely eliminate the problems of comparing different nominal absolute measurements; the solid angles for the di-muon measurements will be the same as for the prompt muon measurements. Such measurements will be made quite easily by varying the target density in the modes we have already used. Since we have made almost the same measurements as we now contemplate, we can, again, be certain that no great difficulties will be encountered.

III. ANALYSIS OF THE DATA

Of course, after the data is collected, the analysis of the data will be made in terms of varieties of models of production constrained to fit the whole of the observations. We can, however, consider now the general characteristics of a first-order analysis and show that it is very likely that a simple analysis of the data will provide an unequivocable answer to the question of the origin of the prompt muons: are the prompt muons produced in pairs or not?

We proceed here by considering the possibility that the muons are indeed produced in pairs and show then that this assumption leads to specific relations between the di-muon observations and the prompt muon measurements which can be tested easily by the data. If muons are produced in pairs, we can define the pair production process as

$$I_g \, (x_g \, , \; p_t \, , \; M_g)$$

where I_g is the production intensity, taken here in the laboratory system for convenience, of the muon pair g, x_g is the ratio of the momentum of the pair to the beam momentum, p_t is the transverse momentum of the pair and M_g is their invariant mass.

The observation that I_μ / I_e, the ratio of prompt electrons to prompt muons, is approximately one, tells us that most of the intensity is derived from pairs where the invariant mass is large compared to the mass of the two muons or $M_g \geqslant 400$ GeV. For such large invariant masses and for $p_t \ll p_L$, which will be the case for these measurements, the muon correlation intensity

$$I_{2\mu} \, (x_1 \, , \; x_2)$$

and the single muon intensity

$$I_\mu \, (x)$$

will depend only upon the angular distribution of the pair decays with respect to the proton beam direction. For many classes of di-muon production this distribution will be essentially isotropic. Indeed, a substantial deviation from isotropy would require not only a large spin for the parent system, but a large alignment of that spin. Then for an isotropic decay distribution (or any specific distribution) a measurement of $I_{\mu}(x)$, the single (prompt) muon intensity, will define the distribution $I_{2\mu}(x_1, x_2)$, the di-muon correlation intensity.

We can express all of this more precisely. Let us assume that the di-muon center of mass has a definite production spectrum:

$$dN_g/dx = F(x) \tag{1}$$

Then the resultant muon spectrum can be written as

$$dN\mu/dx = G(x) = \int_x^1 (dN_g/dx')\ 2\ dx'/x' \quad . \tag{2}$$

The prompt muon flux with momentum greater than x_0 will be:

$$N\mu\ (x_0) = \int_{x_0}^1 G(x)\ dx \tag{3}$$

while the intensity of muon pairs such that each muon has an energy greater than x_0 will be

$$N_{2\mu}\ (x_0) = \int_{2x_0}^1 F(x) \cdot (1 - 2x_0/x)dx \quad . \tag{4}$$

In our experiment, x_0, the minimum muon momentum, will be about 0.1375.

From the measurements$^{(2)}$ of the prompt muon to pion ratios made in the course of Ex. 48, together with our knowledge of the pion spectrum from a variety of experiments,$^{(3)}$ we know the prompt muon spectrum G(x). The knowledge of the shape of the spectrum will be reduced to an absolute spectrum, where the efficiency of the detection system is taken into account, by the measurement of the prompt muons passing through our detection system, $N\mu\ (x_0)$. This measurement, together with the spectrum defined by the previous measurements, will define a value for $N_{2\mu}\ (x_0)$ which will be tested by the experiment. If the prompt muons are produced as di-muons, the measured values of the di-muon flux should be in agreement with the calculated values within an uncertainty of the order of ±30 °/o where this assigned error follows from uncertainties in both the flux measurements and the approximations made in the comparison of the measurements.

IV. EXPERIMENTAL PROCEDURES AND DATA HANDLING

The array of detectors spans an angular acceptance from +35 mr to - 35 mr. Implicitly, we assume that only a negligible prompt muon flux falls at larger angles and that only a negligible proportion of the muons which might make di-muon coincidences are produced at larger angles. Of course, the array is one-dimensional and has a sensible extension only in the horizontal plane. For the prompt muon flux, this is no important constraint as the cylindrical symmetry of the interaction assures us that the intensity detected in the horizontal array is representative of the intensity which falls on any hypothetical linear which lies across the beam line and then the whole prompt muon intensity can easily be calculated from the distribution of intensities detected in the actual array.

It is not so obvious that the linear array can sample the di-muon spectrum in a manner such that the total di-muon intensity can be deduced. This will be the case, however, if the di-muon intensity can be written in the form:

$$I(r_1\ ,\ r_2) = F(\ |r_1 + r_2|\ ,\ |r_1 - r_2|\ ) \tag{5}$$

where the quantities r are the two-dimensional vectors which define the point of intersection of the muons with the plane normal to the beam line which contains the line of detectors. The meaning of Eq. 5, is perhaps best exhibited by considering a limiting case where the muons have the same energy. Then, $|r_1 + r_2|$ will be the transverse momentum of the di-muon and $|r_1 - r_2|$ will be proportional to the invariant mass of the pair. In this limiting case, Eq. 5 simply states that the decay angular distribution of the di-muon is independent of the angle of production. Since we assume that the decay distributions are not very different from isotropy, this result follows from that assumption alone. Specific numerical calculations of production models which are more realistic, suggest strongly that the relaxation of the condition of equal energy of the muons does not much affect the validity of Eq. 5. Since the measurements undertaken with the linear array are sufficient to determine the form of Eq. 5, which can then in turn be used to derive the total di-muon intensity, we conclude that the linear array is sufficient to determine the di-muon flux as well as the prompt single muon flux.

V. LOGISTICS

We will require 75 hrs. of beam time. The actual data taking will go very quickly and take much less than this, but the assembly of checks on backgrounds, accidentals, etc. will require some time. We would hope that this time could be integrated into the remaining time for Ex. 48 to improve flexibility.

We would require the moving of one of the portacamps in the central pit. We would prefer to have the west portacamp moved so as to abut the east portacamp. Such a move can be made while there is beam in proton central for other experiments (e.g., Ex. 288).

For the (rather brief) duration of the experiment, we would like to borrow about 6 duo-quad logic units from PREP.

Everything else is available and will be running as part of our approved experimental program (Ex. 48).

REFERENCES

1. This was discussed by L. Lederman at the International Meeting on Lepton and Photon Interactions; SLAC, Aug. 1975

2. Leipuner et al., to be published in Phys. Rev. Letters. Paper appended.

3. An analysis of the pion spectrum from high energy nucleon-nucleon interactions is given by R.K. Adair, Phys. Rev. Letters 33, 115 (1974)

FIGURE CAPTIONS

Fig. 1	Schematic view of experimental setup. The data presented in Fig. 2 is derived from the counters marked with asterisks.
Fig. 2	Di-muon coincidence rates in the counters represented by asterisks in Fig. 1. The total 6X5 = 30 coincidences from the six counters is reduced to 15 by using the left-right symmetry of the counters and the 15 rates are presented in the figure. In each plane on the figure, an interpolation of the data is used to estimate the coincidence rate of a channel with itself and that rate is marked with an asterisk.

Figure 1

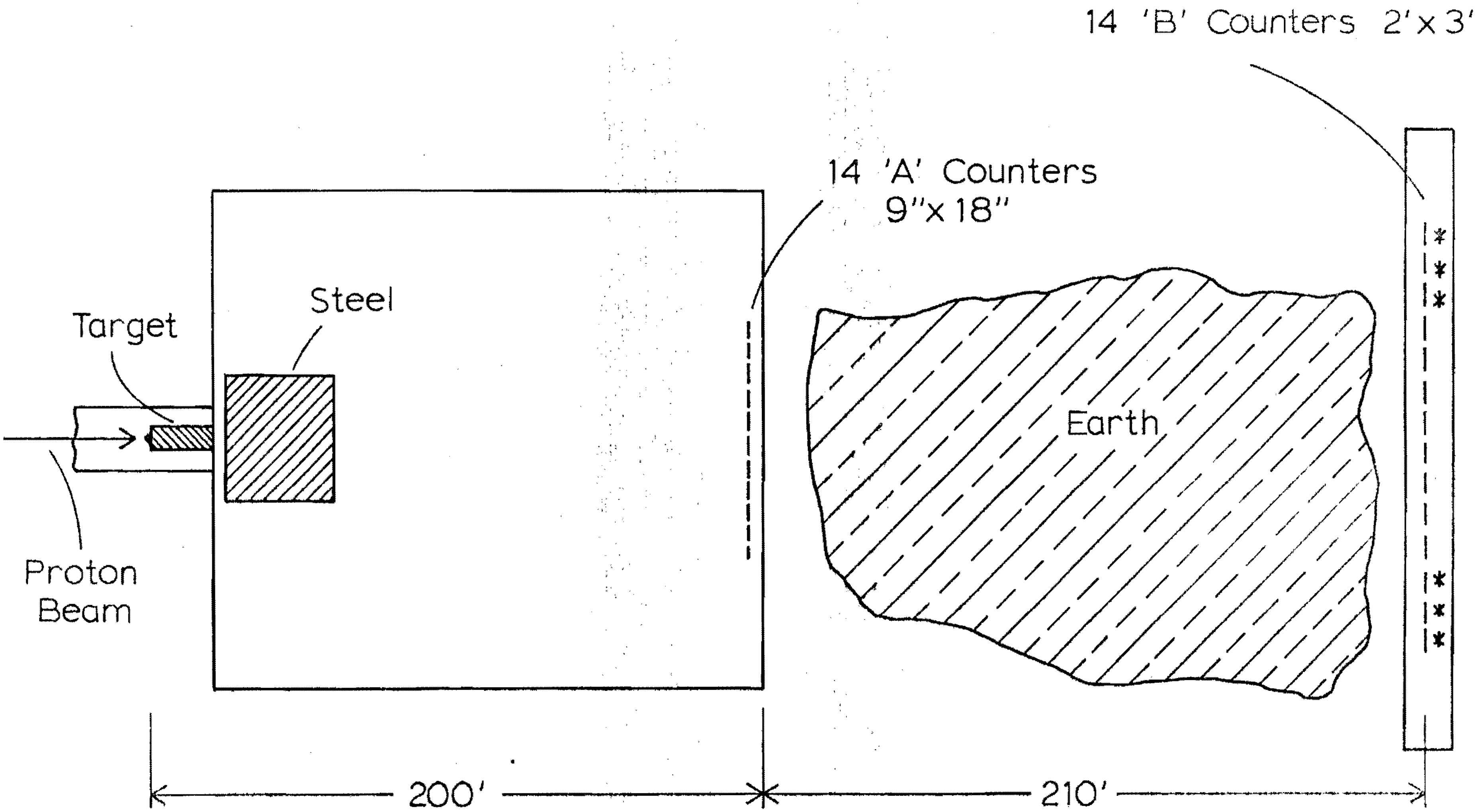
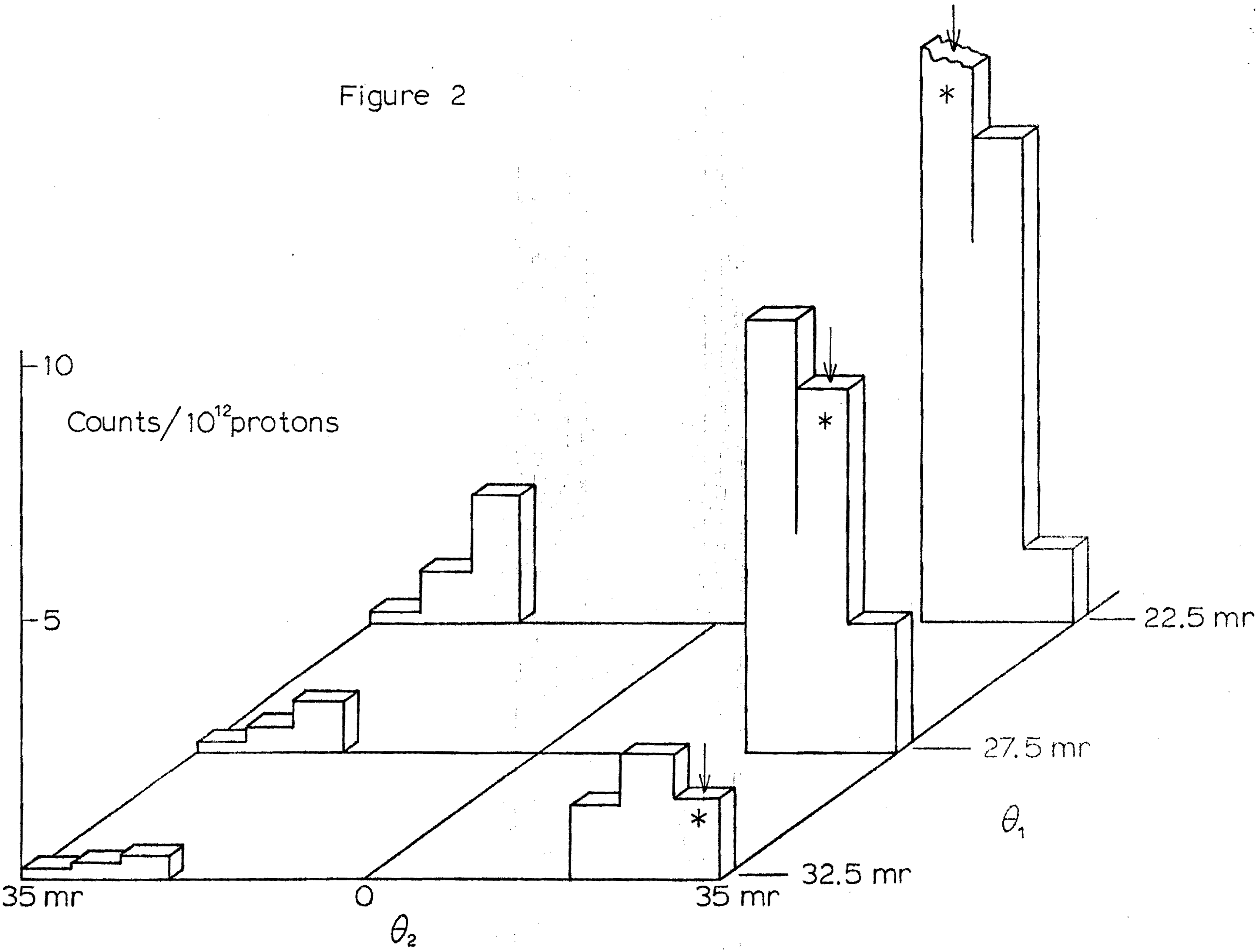

14 'B' Counters 2'x 3'
14 'A' Counters
9"x 18"
Steel
Target
Earth
Proton
Beam
200'
210'

Figure 2



10
Counts/10^{12} protons
5
35 mr
0
35 mr
θ_2
32.5 mr
27.5 mr
22.5 mr
θ_1
*
*
*