NAL PROPOSAL No. 10

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FTS/Commercial 312-231-6600 Ext. 453

A PROPOSAL TO MEASURE THE TOTAL CROSS SECTIONS FOR $\pi^{\pm}$, $K^{\pm}$, P and $\bar{P}$

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ABSTRACT

We propose to measure the total cross sections for $\pi^{\pm}$, $K^{\pm}$, P and $\bar{P}$ on hydrogen and deuterium from 20 GeV/c to approximately 200 Gev/c using a beam in Area 2. We would also measure the absorption cross sections for a few heavier nuclei. Measurements would also be made at higher energies should a more energetic beam be accessible.

A PROPOSAL TO MEASURE THE TOTAL CROSS SECTIONS FOR $\pi^{\pm}$, $K^{\pm}$, P and $\bar{P}$

Recent results[1)] from the Serpukhov accelerator have extended our knowledge of the total cross sections for negative particles up to 65 GeV/c. Many earlier experiments[2)] have measured total cross sections for both positive and negative particles up to 30 GeV/c. We propose to measure the total cross sections for positive and negative particles from 20 GeV/c up to about 200 GeV/c initially and to higher energies when possible. We would concentrate on determining the energy dependence of the cross sections and on a comparison of the particle and antiparticle cross sections.

I. Physics Justification

The Serpukhov experiment measured the total cross sections for π^-, K^- and $\bar{p}$ on hydrogen, deuterium and a selection of heavier elements from helium to uranium. Figure 1, taken from reference 1, is a compilation of total cross sections for hydrogen. The dashed curves are fits to cross sections on neutrons as inferred from the deuterium target data. To within the accuracy of the data, all cross sections have reached constant and unequal values above 30 GeV/c with the possible exception of the antiproton cross sections which may still be decreasing slightly.

There are many different theoretical predictions as to the behavior of total cross sections at high energies. The Pomeranchuk theorem[3)] stipulates that the particle and antiparticle cross sections become equal in the asymptotic region. Assuming charge symmetry, the Serpukhov data for pions provide no evidence that the asymptotic region so defined, is being reached. Likewise the K^-p total cross section is not approaching the K^+p cross section as extrapolated from lower energies, where the K^+p cross section is already constant.

Using the Regge pole model, fits[4] have been made to the data by introducing cuts. These yield cross sections that rise asymptotically to finite values.

In a simple quark model[5], the ratio of the πN and KN cross sections to the NN cross section asymptotically approaches 2/3. The Serpukhov data give 0.6 and 0.5 for $\pi N/NN$ and KN/NN.

Other theories predict that the total cross sections either approach zero[6] or continue to rise logarithmically with energy[7]. No evidence for either of these behaviors is yet visible in the Serpukhov data. In some models the logarithmic rise is predicted to increase to finite limit while in other models it continues to infinity. Such a logarithmic rise should be detectable at NAL energies; Barger and Phillips[8] predict, for example, a 10% increase in the K^+p cross section from 10 to 150 GeV/c.

As part of this experiment we will measure the absorption cross sections for several heavier elements at a few high energy points. We expect this will be sufficient to verify the validity of extrapolating the more detailed Serpukhov data at lower energies. These data show the absorption cross sections for pions and kaons to be essentially energy independent above 20 GeV/c. At a given energy the A dependence is parameterized by:

$$\sigma_{abs.} = \sigma_o A^{\alpha}$$

where α is approximately 3/4 for mesons and 2/3 for anti-protons.

Absorption cross sections would be useful to check the theoretical models[9)] which must be used in calculating the shielding requirements for future NAL experimental areas.

In the course of this experiment we would automatically obtain some information on the particle composition of the beam.

II. Scope of this Experiment

Assuming that only 200 GeV/c protons are transported to Area 2, the upper limits in energy that can be measured there are 200 GeV/c for protons, nearly that for π^-, and approximately 150 GeV/c for π^+, $K^\pm$, and anti-protons. Should it be possible to transport higher energy protons to Area 2, correspondingly higher energy cross sections would be measured.

We request that 500 GeV/c protons be made available, somewhere, so that we can measure the pp cross section to the highest energy possible. For example, this might be done in the external proton beam tunnel before experimental areas are ready.

The points of interest here, the energy dependence of the cross sections and the particle-antiparticle relationship of the cross sections, should be less sensitive to systematic errors than are the absolute values of the cross sections. Systematic errors of 1% are obtainable and statistical errors of 0.1 to 0.2% are achievable and warranted. Methods needed to reach these accuracies are described subsequently.

A major fraction of the equipment required for this experiment is in the incident beam: the Čerenkov counters, the scintillation counters, and beam monitoring equipment. This equipment will be needed by succeeding experiments.

III. Beam

We wish to carry out our experiment up to the highest possible energies available at NAL. Except for this we have no very stringent requirements on the incident beam. Our system is capable of handling a total incident particle rate of 10^6 particles/sec. For positive particles we expect to work with up to 10^6 protons, 10^4 π^+, and 10^3 K^+ per pulse at 150 GeV/c. We expect the π^-, K^- and antiproton intensities to be 10^6, 10^4, and 10^3 per pulse respectively. We can tolerate a beam spot of 1/4" diameter at the focus and a momentum bite of a few percent.

Since we utilize threshold Čerenkov counters instead of differential Čerenkov counters for particle identification, we do not require parallel sections in the incident beam.

IV. Beam Particle Identification

Recent experience at Serpukhov[10)] has demonstrated the feasibility of extending threshold Čerenkov counter techniques to high energies. We propose a simple extrapolation of their techniques to the still higher energies of NAL. The proposed beam layouts at NAL have long drift lengths. In some of these we would replace the vacuum pipe with threshold Čerenkov counters.

The identification scheme involves two 40 m. long, 40 cm. diameter counters set to detect pions but not kaons or protons, and two 15 m. long counters set to detect both pions and kaons but not protons. This would enable us to take data on all three types of beam particles at the same time.

The 5 meter Serpukhov counters were able to identify π's and K's up to 50 GeV/c. In order to extend this to 200 GeV/c we need counters with a factor of 16 greater sensitivity, since $\Delta\beta \propto \frac{1}{p^2}$. By using a photomultiplier with a bialkali photocathode and putting it inside the radiating gas (thereby eliminating any absorption in a window), we will gain at least a factor of 2 in sensitivity. Some of us are involved in building a copy of the Serpukhov counter which we will test with various phototubes at the Argonne ZGS in September, 1970, to find out how large this factor can be. For the present we propose to make the counter 8 times longer than the Serpukhov counters to achieve the total increase of 16 in sensitivity.

We present the following table as indicative of what is required and what one of the 40 meter pion counters we propose would achieve.

P(GeV/c)	$1 - \beta_\pi$	$1 - \beta_K$	$\Theta_c(\pi)$ (radians)	$n_{ph.el.}$	eff. (%)	P(He) (atm)
180	0.27×10^{-6}	3.3×10^{-6}	1.74×10^{-3}	3.6	97	0.094
150	0.42×10^{-6}	5.2×10^{-6}	2.19×10^{-3}	5,7	99.6	0.148
120	0.68×10^{-6}	8.4×10^{-6}	2.78×10^{-3}	9.3	99.99	0.240
90	1.21×10^{-6}	15.0×10^{-6}	3.72×10^{-3}	16.5		0.429
60	2.73×10^{-6}	33.9×10^{-6}	5.58×10^{-3}	25.0		0.94

With two 40 m. long pion counters and two 15 m. long counters counting both pions and kaons we can achieve the following rejection efficiencies.

P(Gev/c)	π Rejection in K Beam	π Rejection in $\bar{p}$ Beam	K Rejection in $\bar{p}$ Beam
180	10^{-3}	10^{-6}	10^{-3}
150	2×10^{-5}	10^{-9}	2×10^{-5}
120	1×10^{-8}	——	10^{-8}

V. Layout of Experimental Apparatus

For the measurement of total cross sections we propose to use the transmission technique. The plan of the experimental apparatus is shown in Fig. 2. The beam particles would be defined by scintillation counters and four threshold Čerenkov counters.

The target will be H_2, D_2 or an empty container. A two meter target length is planned. We will take special care in the construction of the targets to reduce boiling so that the density is held constant, as has been done in the past.

Following the target at a distance varying from 70 to 250 feet would be the transmission counters T_1-T_{10}. A pair of small counters, SM_1 and SM_2, could continuously monitor the efficiency of the transmission counters. Counters T_1-T_{10} range in diameter from 1 inch to 10 inches. The distance of these counters from the target would be varied with incident beam energy so that T_4 would cover a $|t|$ range from 0 to $0.04 (\text{GeV/c})^2$, to minimize energy dependent errors in the extrapolation to t=0. The size of the smallest counter used in the extrapolation must be large enough to contain fully the Coulomb scattering peak and Coulomb nuclear interference, but small enough to count only a small part of the strong interaction processes.

The transmission counters will be mounted on a carriage and rail system to facilitate accurate positioning. Behind the transmission counters will be placed an arrangement of iron absorbers and counters to allow measurement of muons in the beam.

VI. Counting Rate and Statistical Accuracy

The partial cross section for the i-th transmission counter is defined as

$$\sigma_i = \sigma_{tot} - \sum_k \int_{\Omega_i} \frac{d\sigma_k}{d\Omega_i}(\theta)\, d\Omega$$

The differential cross section $\frac{d\sigma_k}{d\Omega}(\theta)$ represents the angular distribution of charged secondaries for a reaction channel k. The sum is taken over all possible channels and the integration is made over the solid angle subtended by the i-th counter.

The number of counts in the i-th counter with the target full is given by

$$N_{if} = M_f \, g_i \, \exp(-n\sigma_i)$$

where M_f is the incident flux, n is the number of nuclei per cm^2 in the target. The factor g_i accounts for losses other than those due to the interaction in the target material, such as the interactions in the target container, the decay of the scattered particles, or the inefficiency of our detection system. If one assumes that these losses are the same for the target full and the target empty,

$$g_i = \frac{N_{ie}}{M_e}$$

where the subscript e refers to measurement with the empty target. Since $n\sigma \ll 1$ is our present experimental condition, each counter will see essentially all the particles in the beam.

The total cross section will be obtained from an extrapolation of the partial cross section

$$\sigma_i = \frac{1}{n}\{\ln N_{ie} - \ln N_{if} + \ln M_f - \ln M_e\}$$

Taking $N_{ie} \approx N_{if} \equiv N$

$$\frac{\Delta\sigma_i}{\sigma_i} = \frac{\sqrt{2}}{n\sigma_i} \; \frac{\Delta N}{N}$$

In order to achieve a statistical accuracy of $\pm.1\%$ in the partial cross sections we need $N = 5 \times 10^7$ counts, with both full target and empty target. At 10^6 particles per pulse this represents 100 pulses or $\sim$10 minutes of running time. At the level of 10^4 particles per pulse, this represents $\sim$10 hours of running time.

VII. Electronics

The beam flux on the target is defined by the signal $f_o = S_1\bar{A}_1S_2S_3S_4S_8\bar{A}_2$. The electronic deadtime of the system is determined by the circuits of S_1 and S_2, which have the highest counting rate. The counters S_5 and S_6 with slow linear output pulses have their thresholds set to detect pulses which correspond to 1.5x minimum ionization. These are used as a veto to eliminate two-particle accidental coincidence effects. To eliminate two particle transmission counter deadtime effects, S_7 which intercepts all the beam that reaches the transmission counters is set with a long deadtime and put in coincidence with the beam telescope; thus, the accepted signal is $f_b = S_7(\bar{S}_5\cdot\bar{S}_6)\cdot f_o$.

The identity of individual particles is established through appropriate Cerenkov counter conditions; e.g. $f_{(\pi)} = f_b\cdot C_{\pi_1}C_{\pi_2}C_{K_1}C_{K_2}$, $f_{(k)} = f_bC_{K_1}C_{K_2}\bar{C}_{\pi_1}\bar{C}_{\pi_2}$ and $f_{(p)} = f_b\bar{C}_{\pi_1}\bar{C}_{\pi_2}\bar{C}_{K_1}\bar{C}_{K_2}$.

The effect of counter logic configuration and pressure fluctuations on the cross sections will be measured and minimized. The beam intensity will be varied to check on systematic rate dependent effects.

The appropriate beam signal $f_{(j)}$, where $j=\pi$, K, or p, is put in coincidence with adjacent pairs of transmission counters; i.e., $f_{(j)}*(T_i*T_{i+1})$ to eliminate counting from the light guides and random accidentals. Residual accidentals can be monitored by delayed and variable resolution time coincidence circuits. The efficiency of the transmission counters and the beam position is constantly monitored by the signal

$f_{(j)}*(T_i*T_{i+1})*SM_1*SM_2$.

Correction of the cross sections for the muon contamination will be made in two ways. In the first procedure, the muon flux in the beam will be measured with the absorber telescope $S_9 \ldots S_{14}$. Systematic effects in the correction will be studied with the absorber telescope. The cross sections taken without a muon veto will be renormalized.

In the second procedure, we will apply a muon veto signal to the signal $f_{(j)}$ using the absorber telescope. Through a variation of the composition of the telescope veto signal, systematic effects of the muon correction imposed by the telescope on the cross sections can be determined and minimized. At NAL energies these systematic effects should be small compared to lower energies.

VIII. Sources of Equipment

The apparatus required for this experiment is general purpose and is likely to be used by succeeding experiments. The Čerenkov counters need only withstand an external pressure of one atmosphere and do not require optical alignment over their entire length. The total of 400 feet of pipe can be welded in place. The only requirement is that there be no large temperature variations along their length. The three target containers (for hydrogen, deuterium and empty) along with their refrigerators can be purchased commercially. We assume this equipment will be part of NAL's experimental facilities. No extra magnets will be needed. The standard logic circuitry and the capacity to provide scintillation counters are already available in our Physics Research Section.

IX. Running Time

We request 400 hours of data taking time plus 50 hours of testing time after the secondary beam has been focused onto our target. In this period we plan to measure pion and proton cross sections in relatively small energy steps and then to dwell at several of these for a time sufficient for high statistical accuracy for kaons and antiprotons.

REFERENCES

1. J. V. Allaby, Yu.B. Bushnin, S. P. Denisov, A. N. Diddens R. W. Dobinson, S. V. Donskov, G. Giacomelli, Yu.P. Gorin, A. Klovning, A.I. Petrukhin, Yu.D. Prokoshkin, R.S. Shuvalov, C.A. Stahlbrandt, D.A. Stoyanova, Physics Letters 30 B, 500 (1969) and Yadernaya Fisika(to be published)- the latter appears in English translation as CERN, NP Internal Report 70-4 (1970).

2. G. von Dardel, D. Dekkers, R. Mermod, M. Vivargent, G. Wever and K. Winter, Phys. Rev. Letters 8, 173 (1962).

   W. F. Baker, R. L. Cool, E. W. Jenkins, T. F. Kycia, R. H. Phillips and A. L. Read, Phys. Rev. 129, 2285 (1963).

   W. F. Baker, E. W. Jenkins, T. F. Kycia, R. H. Phillips, A. L. Read, K. F. Riley and H. Ruderman, Proc. Int. Conf. on Elementary Particles and High-Energy Physics, Sienna (1963), Vol. I, P. 634.

   W. Galbraith, E. W. Jenkins, T. F. Kycia, B. A. Leontic, R. H. Phillips, A. L. Read and R. Rubinstein, Phys. Rev. 138 B, 913 (1965).

   A. Citron, W. Galbraith, T. F. Kycia, B. A. Leontic, R. H. Phillips, A. Rousset and P. H. Sharp, Phys. Rev. 144, 1101 (1966).

   D.V. Bugg, D. C. Salter, G. H. Stafford, R. F. George, K. F. Riley and R. J. Tapper, Phys.Rev. 146, 980 (1966).

   K. J. Foley, R. S. Jones, S. J. Lindenbaum, W. A. Love, S. Ozaki, E. D. Platner, C. A. Quarles, E. H. Willen, Phys. Rev. Letters 19, 330, 857 (1967).

3. I. Ia. Pomeranchuk, Zhur. Eksp. i Teoret. Fiz. 34, 725 (1958) [English Translation: Soviet Phys. - JETP 7, 499 (1958)].

4. V. Barger and R. J. N. Phillips, Phys. Rev. Letters 24, 291 (1970).

   A. N. Lendel and K. A. Ter-Martirosian, JETP Letters 11, 70 (1970).

5. F. M. Levin and L. L. Frankfurt, Soviet Phys. - JETP Letters 2, 65 (1965)

   H. J. Lipkin and F. Scheck, Phys. Rev. Letters 16, 71 (1966).

6. N. Cabibbo, L. Horwitz, J. J. J. Kokkedee and Y. Néeman, Nuovo Cimento 45 A. 275 (1966).

   H. Cheng and T. T. Wu, Phys. Rev. Letters 22, 1405 (1969).

7. S. Frautschi and B. Margolis, Nuovo Cimento 56 A, 1155 (1968) N. W. Dean, Phys. Rev. 182, 1695 (1969).

V. N. Gribov and A. A. Migdal, Yadernaya Fisika 8, 1213 (1968). [English Translation: Soviet Journal of Nuclear Phys. 8, (1969)].

V. R. Garsevanishvili, V. A. Matveev, L. A. Slepchenko and A.N. Tavkhelidze, JINR Preprint E2-4251 (1969).

8. V. Barger and R.J. N. Phillips, Univ. of Wisconsin preprint C00-887-262 (1970) (to be published).

9. J. Pumplin and M. Ross, Phys. Rev. Letters 21, 1778 (1968).

10. Yu.P. Gorin, S. P. Denisov, S.V. Donskov, A.F. Dunaitsev, A.I. Petrukhin, Yu.D.Prokoshkin, R.S. Shuvalov and D.A. Stoyanova, Preprint IHEP-69-63.

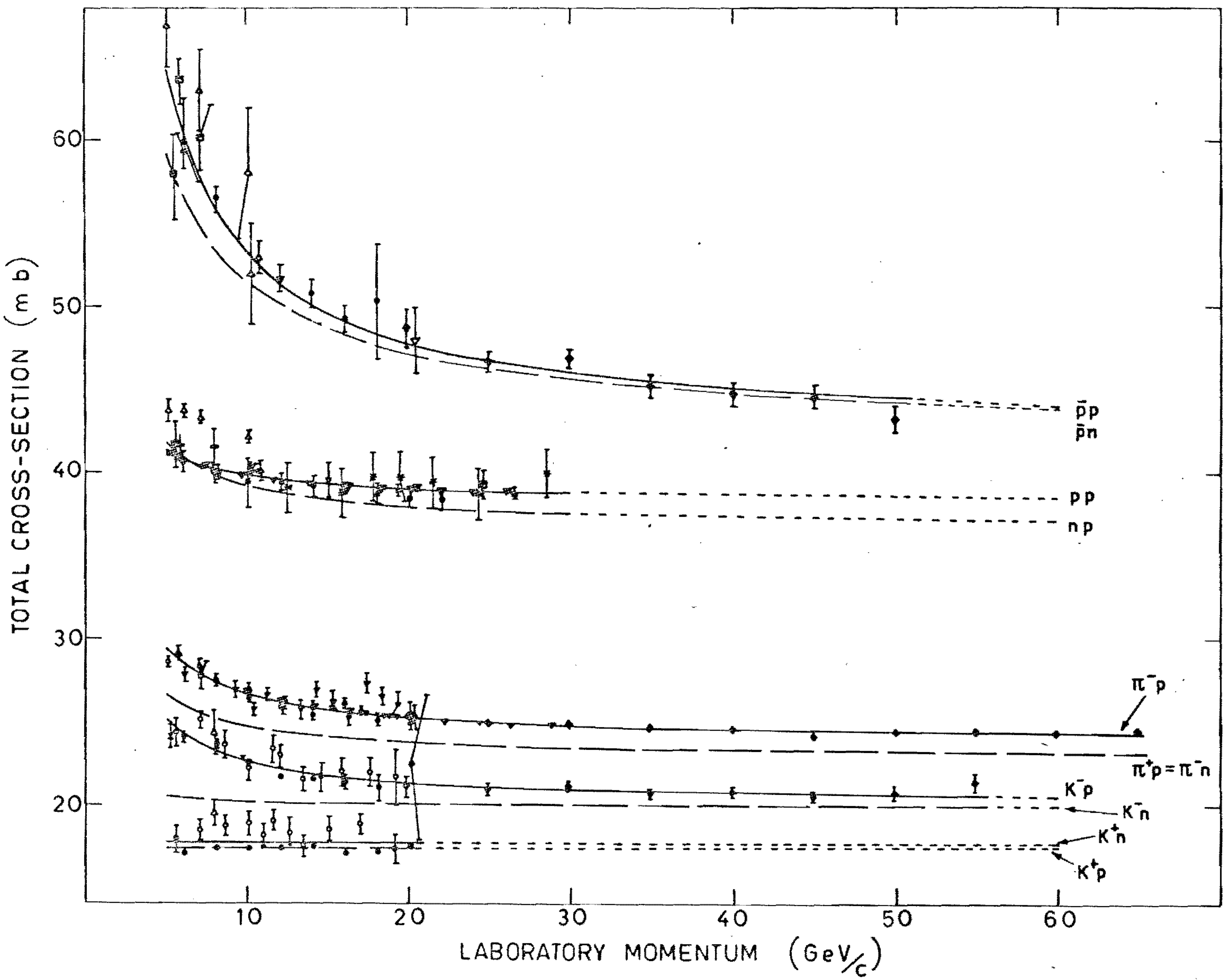
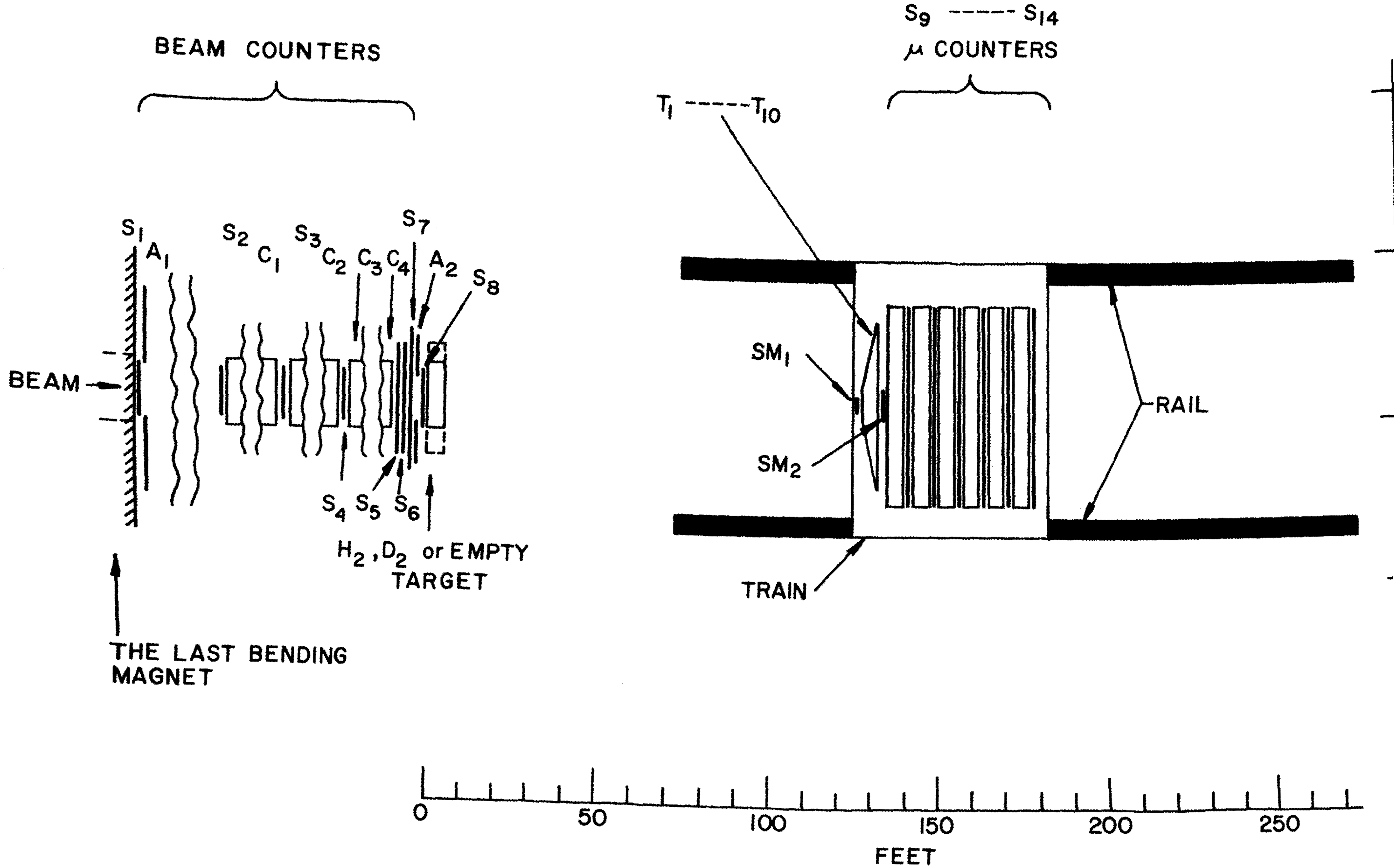
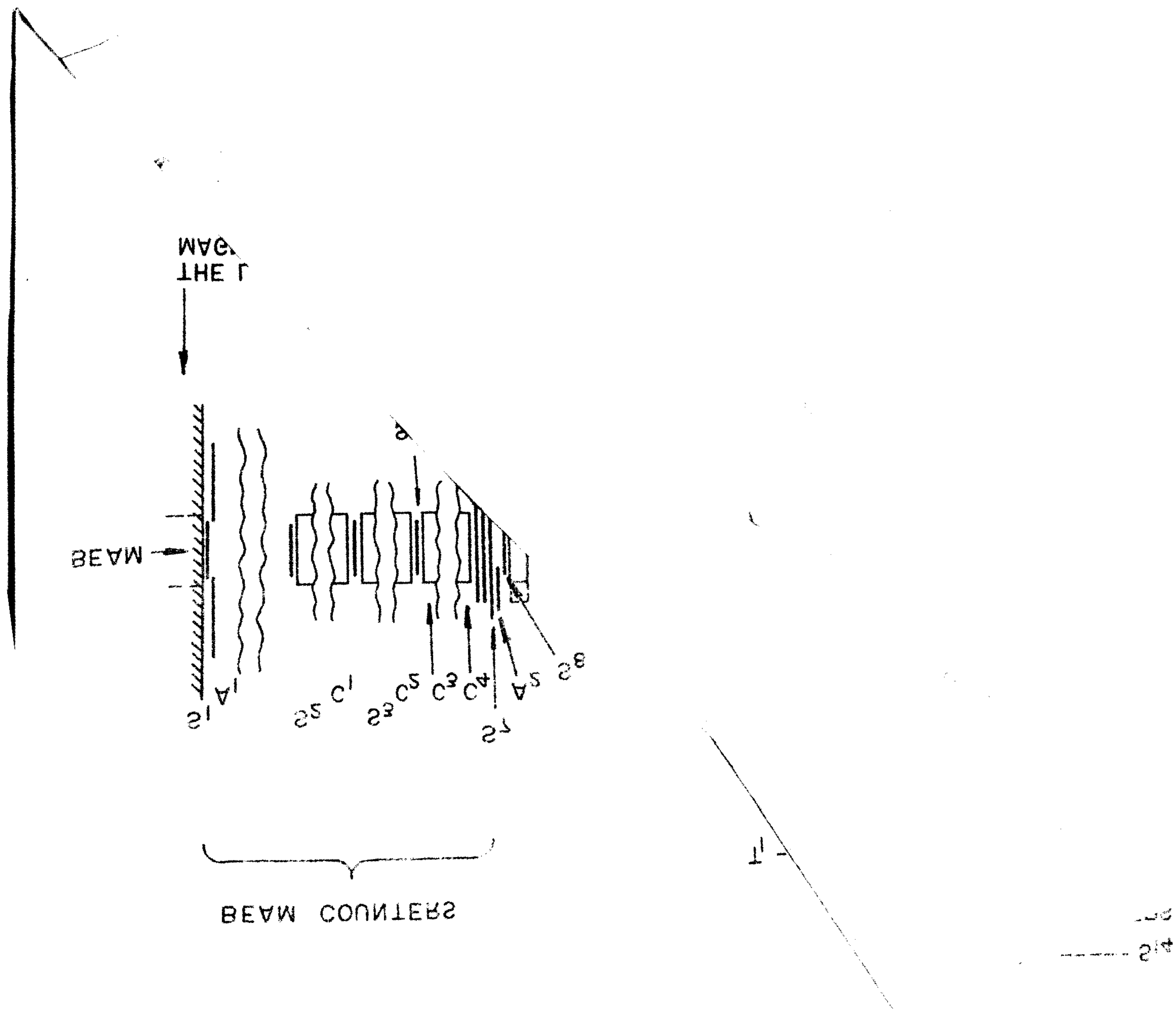

TOTAL CROSS-SECTION (mb)
60
50
40
30
20
10
20
30
40
50
60
LABORATORY MOMENTUM (GeV/c)
p̄p
p̄n
pp
np
π⁻p
π⁺p = π⁻n
K⁻p
K⁻n
K⁺n
K⁺p

Fig:1



BEAM COUNTERS
S_9 ------ S_{14}
μ COUNTERS
T_1 ------ T_{10}
S_1
A_1
S_2
C_1
S_3
C_2
C_3
C_4
S_7
A_2
S_8
BEAM
S_4
S_5
S_6
H_2, D_2 or EMPTY TARGET
THE LAST BENDING MAGNET
SM_1
SM_2
RAIL
TRAIN
0
50
100
150
200
250
FEET

FIGURE 2


THE L
MAG
BEAM
S1
A1
S2
C1
S3
C2
C3
C4
S7
A2
S8
BEAM COUNTERS
T1
S14