CERN - EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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CERN/PSC-77/11
PSC/P 4
4 February 1977

PROPOSAL

HIGH PRECISION MEASUREMENT OF $\pi^- p$ TOTAL CROSS SECTION

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ABSTRACT

We propose an addition to the CERN-CDF experiment S153(**), aiming to measure with a high momentum resolution $\sim$ 0.1% and a good statistical accuracy $\sim$ 0.1% the total cross section of the $\pi^- p$ scattering, in the 5-15 GeV/c momentum range. This measurement yields a complementary information on the possible existence and the nature of narrow baryon states in the 3.2 to 5.4 GeV mass range. It allows also to detect N^* and Δ Regge recurrences. Part of the existing apparatus will be used in parallel with the S153 experiment. Proportional chambers acting as a transmission hodoscope have to be added. A data flow of $\sim$ 40 Megabit/s originated in wire chambers, will be processed on-line and the events will be histogrammed by the fast micro-computer developed at Ecole Polytechnique. The data will be taken essentially during the running time of experiment S153 without interfering with it.

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(**) Cf. proposal to the EEC, CERN/EEC 76-6 (28 January 1976).

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INTRODUCTION

We propose a new type of measurement of the total cross section (σ_{tot} $\pi^- p$) based on the use of the new technology of fast microprocessors together with the high momentum resolution beam developed for the S153 experiment.

The first interest of this measurement is its ability to study narrow structures of the σ_{tot} $\pi^- p$ as a function of energy, even with low amplitudes. It will complement the hunt for narrow-baryon formation in the large angle elastic scattering done by the S153 experiment, because the sensitivity to the various resonance parameters - spin, width, elasticity - are quite different in both cases (see Appendix).

In short, σ_{tot} is relatively more sensitive to high-spins and high inelasticities, but its absolute sensitivity is much more affected by the presence of non-resonant amplitudes.

The second interest of this measurement is a good control over the systematic errors in order to detect clearly the oscillation of σ_{tot} due to the Regge-recurrences of Δ and N^* resonances.

From a practical point of view the cost of this experiment will be kept at a minimum by using the same particles and a large part of the equipment of the S153 experiment.

1. THE MEASUREMENT OF $\pi^- p$ TOTAL CROSS SECTION

In the experiment S153 the incident beam momentum will be measured with an accuracy of about 5×10^{-4}. Taking into account the uncertainty coming from the energy loss in the 25 cm liquid hydrogen target this precision will allow a total cross section measurement of $\pi^- p$ hadronic interactions with a incident momentum step $\Delta p = 10^{-3}$ p for an incident momentum p ranging from 5 GeV/c to 15 GeV/c.

1.1 Principle of the measurement

As in previous experiments (see for instance refs [1-4] we will use the transmission method measurement: by measuring the direction of the beam particle before and after the target one is able to determine if this particle has made a hadronic interaction or not in the target. This is done by looking at the scattered angle and by making a cut in the t of the associated elastic reaction.

The effect of interaction with the wall of the target and decay of incident particle is taken into account by taking data with the target full of hydrogen and empty. Neglecting all corrections the total cross section can be then written as

$$\sigma_{tot} = - \frac{1}{n_p} \log \left(\frac{N^F_{out}}{N^{MT}_{out}} \cdot \frac{N^{MT}_{in}}{N^F_{in}} \right)$$

Where the upper indices F and MT refer to target full and empty, the numbers N_{in} and N_{out} refer to the number of incident π and corresponding unscattered outgoing π, n_p is the number of proton by unit of surface crossed by each incident particle in the liquid hydrogen target.

Corrections have to be made on N_{out} in order to take into account the elastic events kept inside the cut in t. The correction is evaluated by measuring the differential cross section for larger values of t and by simple extrapolation determining the number of elastic events inside the t cut. Other corrections coming from nuclear Coulomb interference and from simple or multiple scattering are easily evaluated from the theory [1,2] and available data.

In our experiment the measurement of the incident particle will be done using the two last multiwire proportional chambers of the S153 beam spectrometer. The measurement of the outgoing particle will be done by two MWPC WF1 and WF2 placed after the target on the beam line and close to each other.

1.2 Extrapolation procedure

Compared to previous measurements the use of MWPC before and after the target will give a better precision on t-measurement ($\Delta t/t \sim 4\%$) and will allow a good extrapolation inside the small $|t|$ region. It will also give a good control over the effects coming from simple and multiple

Coulomb scattering. We will thus reduce a major source of systematic errors which was still present in refs [1] and [2].

1.3 Efficiency of the MWPC

It is a crucial point in a transmission measurement not to miss any particles which are inside the t cut because it affects directly the precision in the measurement. The detection inefficiency must be smaller than the precision of measurement or at least known accurately. For that reason two MWPC, WF1 and WF2, will be put one after the other in the beam line (cf. fig. 1), the first one (256 x 256 mm) will have 2 mm spacing and will cover a large region of t, the other one smaller (128 x 128 cm) 1 mm spacing, will measure the small t-region and cover the part inside the t-cut. The particles having a small t will be looked at by two multiwire proportional chambers and should be detected with an inefficiency less than 10^{-3}. This inefficiency will be measured and monitored permanently by an array of 5X and 5Y scintillator counters situated after WF1 and WF2. We then expect to keep the relative systematic errors coming from the detection inefficiency near 10^{-4}.

1.4 Density and length of the target

The target will be of the same type as the ones used in refs [1,2] although much smaller (25 cm). It will have a separated cooling jacket with boiling liquid hydrogen surrounding the actual hydrogen interaction volume. This liquid hydrogen will be slightly pressurized and kept free of bubble. Its temperature will be permanently monitored by a liquid hydrogen gauge which will measure the temperature and will give the density with a precision of 10^{-4}.

The length of the target will be measured first at room temperature and second by using the two arms of the experiment S153. The mylar window will be made as flat as possible and we will use the measurement of the incident particle to determine the effective hydrogen length and compensate for the remaining spherical shape of the mylar windows.

We then expect an overall absolute normalization precise to a few part per 10^3 and a relative normalization between each measurement points with a precision of one part per 10^4.

1.5 Beam contamination

Due to the high intensity of the beam ($\sim 5 \times 10^6\ \pi^-$/burst), no direct separation by a simple Cerenkov counter can be done between K^-, $\bar{p}$ and π^-. Nevertheless, the direct contamination being of the order of 2% for K^- and 0.4% for $\bar{p}$ a measurement of this contamination can be easily done with a reduced intensity on the primary target and a threshold Cerenkov counter. Using known cross sections for K^- and $\bar{p}$ we can then correct with a good accuracy (better than 10^{-4}) the measured $\pi^- p$ total cross section.

The μ contamination will be determined with an iron μ-filter placed in the beam line and the normalization of the incident flux will be corrected accordingly.

1.6 π-decay

π-μ-decay effects will be suppressed by the empty target subtraction. Nevertheless, the iron μ-filter will enable us to investigate possible systematic effects coming from differences of behaviour of π or μ in liquid hydrogen and vacuum.

1.7 Statistical precision

One of the original features of the equipment is the use of the new microprocessor technique which will enable us to accumulate a much higher number of events than in previous experiments. We plan to accumulate enough events to have a statistical accuracy in each incident momentum bin better than one part per thousand. In other terms, we will look at 5×10^7 π^- incident particles for each bin, the separation between bins being 10^{-3} times the central value of the incident momentum. The final result of the experiment will then have the same kind of precision as for instance ref. [2], but with a number of total cross section measurements for a given momentum interval twenty times higher.

2. THE MICRO-COMPUTER

2.1 Hardware

We have developped a fast micro-computer around the AM2900 microprocessor family running at 130 ns per instruction (45 ns/equivalent cycle). Then we have designed a fast encoder of MWPC data which is adapted to the micro-computer (figs 2-3): the encoding of a simple event, 1 wire per chamber, lasts 55 ns and the result is found directly in the micro-computer memory. This corresponds to an instantaneous data flow of 800 Megabits/s while the average data flow is limited by the computing speed to 40 Megabits/s. By comparison the same figures for a CAMAC link to a minicomputer operated at maximum speed would be 30 times smaller. The connection of the micro-computer to the external world is done through a CAMAC link to a mini-computer.

2.2 Software

Basic micro-software is deliberately kept at a minimum. This minimum consists of an assembler language written in FORTRAN. The resulting object code is then transferred to the micro-computer by the mini-computer connected to it which also helps debugging. Several application programs have been prepared for the experiment:

- wire chamber and timing tests,
- beam profiles,
- calibration of the relative positions of the wire chambers.

The main program histograms the events for the σ_{tot} measurement. It will comprise two cycles: (a) the short cycle to separate the unscattered beam track from the others (see part 1.); only a small fraction of these "straight-through" events will suffer the long cycle and, (b) the long cycle to compute the value of $\Delta p/p$ of the deflection of the track inside the target and to histogram these quantities according to the prescriptions of sect. 1. A special treatment of pathological cases such as a missing intercept in one plane or two distinct ones, will be implemented in order to understand and evaluate the most important sources of systematic errors

2.3 Performances

The performances of the micro-computer are directly affecting the σ_{tot} measurement:

(a) They determine the statistical accuracy because statistics are limited by the computing speed. Assuming from sect. 1 a ratio of long cycles/short cycles smaller than 0.1, we are able to treat $\sim 2\ 10^5$ events/sec. This is much less than the event rate supplied by the beam, but much more than that with classical techniques.

(b) They allow a detailed treatment of pathological cases, and a fine binning of the beam momentum.

3. FINANCIAL ASPECTS AND SCHEDULE

It is suggested that the two MWPC's should be built at CERN. The micro-computer will be built at Ecole Polytechnique. Table I (page 8) displays the proposed sharing of the costs. We aim to begin our set-up at CERN near the end of 1977.

TABLE I

	CERN	X
2 MWPC's		
mechanics	20.0 KSF	
preampli	7.5 KSF	
alim. gas + Divers	7.5 KSF	
CABLES		
cables	20.0 KSF	
connectors	15.0 KSF	
wiring	15.0 KSF	
ELECTRONICS		
(micro-computer et al.)		
components		50.0 KSF
connectors		10.0 KSF
wiring		60.0 KSF
power supplies		25.0 KSF
racks		15.0 KSF
pool	20.0 KSF	
TOTALS	105.0 KSF	160.0 KSF

GRAND TOTAL = 265.0 KSF.

APPENDIX

SENSITIVITY OF A σ_{tot} MEASUREMENT TO A NARROW RESONANCE STRUCTURE

The contribution of a resonance to the two-body $\pi^- p$ total cross section can be written as

$$\sigma_{tot}(E) = \sigma_{bkg}(E) + \sigma_{res}(E)$$

where E is the total incident energy, σ_{bkg} represents the contribution of the non resonating part, σ_{res} represents the resonating contribution which should have a rapid variation with E. One can parametrise σ_{res} as follows:

$$\sigma_{res}(E) = 4\pi\lambda\!\!\!^{-2}\ (J + 1/2)\ x \frac{1}{1 + \varepsilon^2} \qquad (1)$$

where J is the spin of the resonance, $\lambda\!\!\!^{-} = \hbar/P_{cm}$ is the wave length associated to the incident energy E, x is the branching ratio of the resonance through the $\pi^- p$ channel, ε is the energy difference with respect to the resonance energy E_r in unit of $\Gamma/2$ [$\varepsilon = 2(E_r - E)/\Gamma$] Γ being the total resonance width.

Let us call ΔE our total incident energy binning. At 10 GeV incident momentum we have $\Delta E = 2000$ KeV, $E = 4.43$ GeV, $4\pi\lambda\!\!\!^{-2} = 1.1$ mb, $\sigma_{bkg} = 25$ mb. Let us suppose also that the error $\Delta\sigma$ on σ_{tot} is $10^{-3} \times \sigma_{tot}$ ($\Delta\sigma = 25\ \mu b$). Let us now consider a strategy to find and establish a narrow structure in total cross section.

In the proposed beam of experiment S153 the momentum bite is ± 2% since our binning width corresponds to $1\,^{o}/oo$ the incident momentum. For each run we will measured simultaneously 40 values of the total cross section. If we take as a possible candidate for new resonance every three standard deviation bump, we will have one random candidate every ten runs. By repeating all three standard deviation runs we can suppress all statistical effect and keep only the genuine ones.

In that context we can define our sensitivity for finding a resonance for two situations.

A1. Cases where $\Gamma >> \Delta E$

We may request here only a one-standard deviation at the maximum value of σ_{res} because, if $\Gamma > 3\Delta E$, we should still have a three-standard deviation effect by combining all the bins inside the resonance width. In that case our sensitivity is given by $\sigma_{res}(E_r) > \Delta\sigma_{tot}$ which gives 10 GeV/c incident momentum

$$\boxed{x(J + 1/2) > 3} \quad \text{where x is in per cent.} \qquad (2)$$

It means for instance that we should see a resonance with $x > 1.5\%$, $J = 3/2$ and $\Gamma > 6000$ KeV.

A2. Cases where $\Gamma << E$

We have to average σ_{res} over the energy bin in order to compare to σ_{bkg}

$$\sigma_{res}^{av} = \frac{1}{\Delta E} \int_{E_R - \frac{\Delta E}{2}}^{E_R + \frac{\Delta E}{2}} \sigma_{res} \, dE \simeq \frac{1}{\Delta E} \int_{-\infty}^{+\infty} 4\pi ƛ^2 (J + 1/2) \frac{dE}{1 + \left(2\frac{E_R - E}{\Gamma}\right)^2}$$

which gives

$$\boxed{\sigma_{res}^{av} = 2\pi^2 ƛ^2 (J + 1/2) \frac{\Gamma x}{\Delta E}} \quad . \qquad (3)$$

For having a three-standard deviation effect we should have $\sigma^{av}_{res} > 3\Delta\sigma_{tot}$ which leads with the preceding figures to

$$\boxed{x\Gamma(J + 1/2) > 8000} \tag{4}$$

where x is in per cent Γ in KeV. If $\Gamma = 500$ KeV and $J = 3/2$ we have $x > 8\%$.

A3. Comparison with the wide angle measurement (S153)

For $J = 1/2$ if one adopts the same strategy in experiment S153 as the one defined here, S153 is more sensitive to narrow resonance. For instance for a narrow resonance ($\Gamma < 100$ KeV) we have here a limitation to $\Gamma x > 8000$ against in the same condition a $\Gamma x^2 > 300$ for S153 with x in per cent Γ in KeV. But if any resonance is found by S153, the total cross section measurement could give a good confirmation if we increase locally the statistic.

Nevertheless, for greater values of J, S153 looking at large scattering angles becomes less sensitive to resonant behaviour where as due to the $J + 1/2$ factor the cross section measurement experiment sees its sensitivity increase and becomes much more efficient than S153.

REFERENCES

[1] R.J. Cool et al., Physics Review D1 (1970) 1877.

[2] A. Citron et al., Physics Review 144 (1966) 1101.

[3] K.J. Forley et al., Phys. Rev. Letters 19 (1967) 330.

[4] W. Galbraith et al., Phys. Review 138B (1975) 913.

[5] P. Baillon et al., Yellow Report, CERN 75-10.

FIGURE CAPTIONS

Fig. 1 Layout of the experiment (beam excluded).

Fig. 2 General layout of the electronics.

Fig. 3 Microcomputer architecture.

Fig. 4 Example of the elastic differential cross section near $t = 0$ for $\pi^- p$ at 2 GeV from ref. [5]. The thick solid curve represents the sum of the nuclear and coulomb scattering. The triangle is the optical point. The inset shows details in the low t region. The thin solid curve represents the nuclear scattering contribution, the dash-dotted curve the coulomb scattering contribution and the dotted curve the absolute value of the interference term.

Fig. 5 Existing measurement in $\pi^- p$ total cross section between 5 and 15 GeV/c.

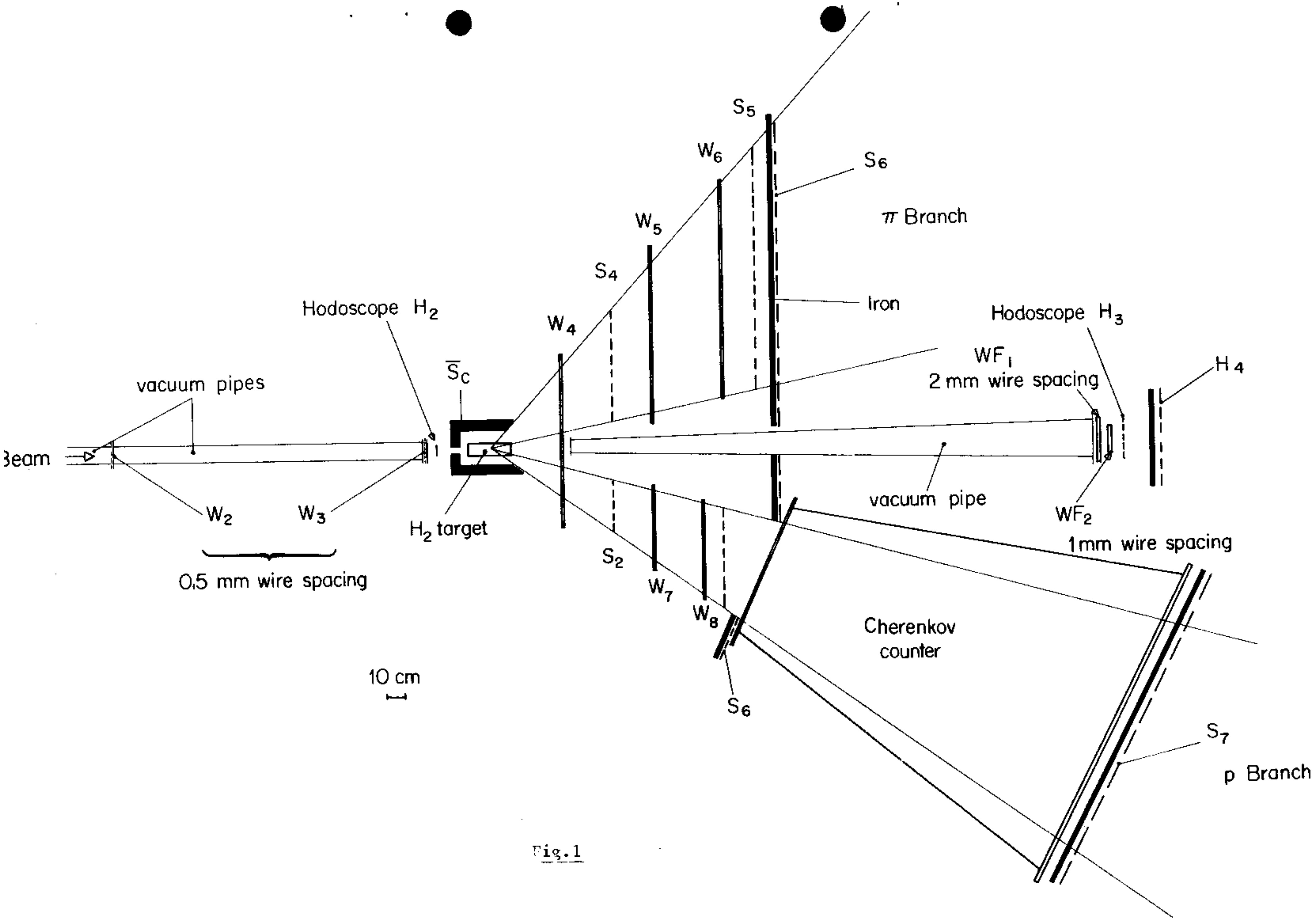
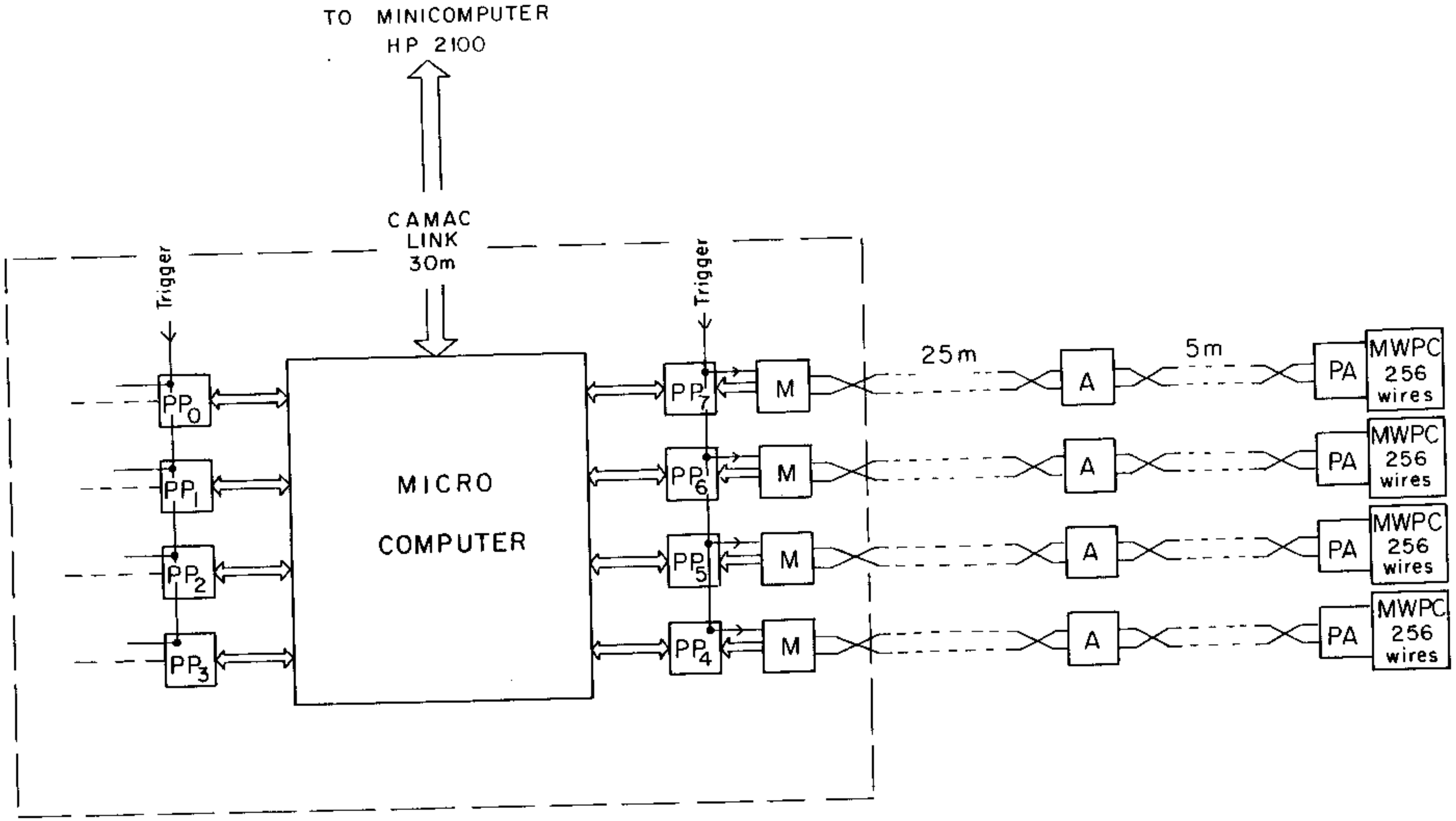

S5
W6
S6
π Branch
W5
S4
Iron
Hodoscope H2
W4
Hodoscope H3
WF1
2 mm wire spacing
H 4
$\overline{S}_C$
vacuum pipes
Beam
W2
W3
H2 target
vacuum pipe
WF2
S2
W7
W8
1mm wire spacing
0,5 mm wire spacing
Cherenkov counter
10 cm
S6
S7
p Branch

Fig.1



PP : peripheral processor
M : memory
A : amplifier discriminator
PA : preamplifier

Fig. 2

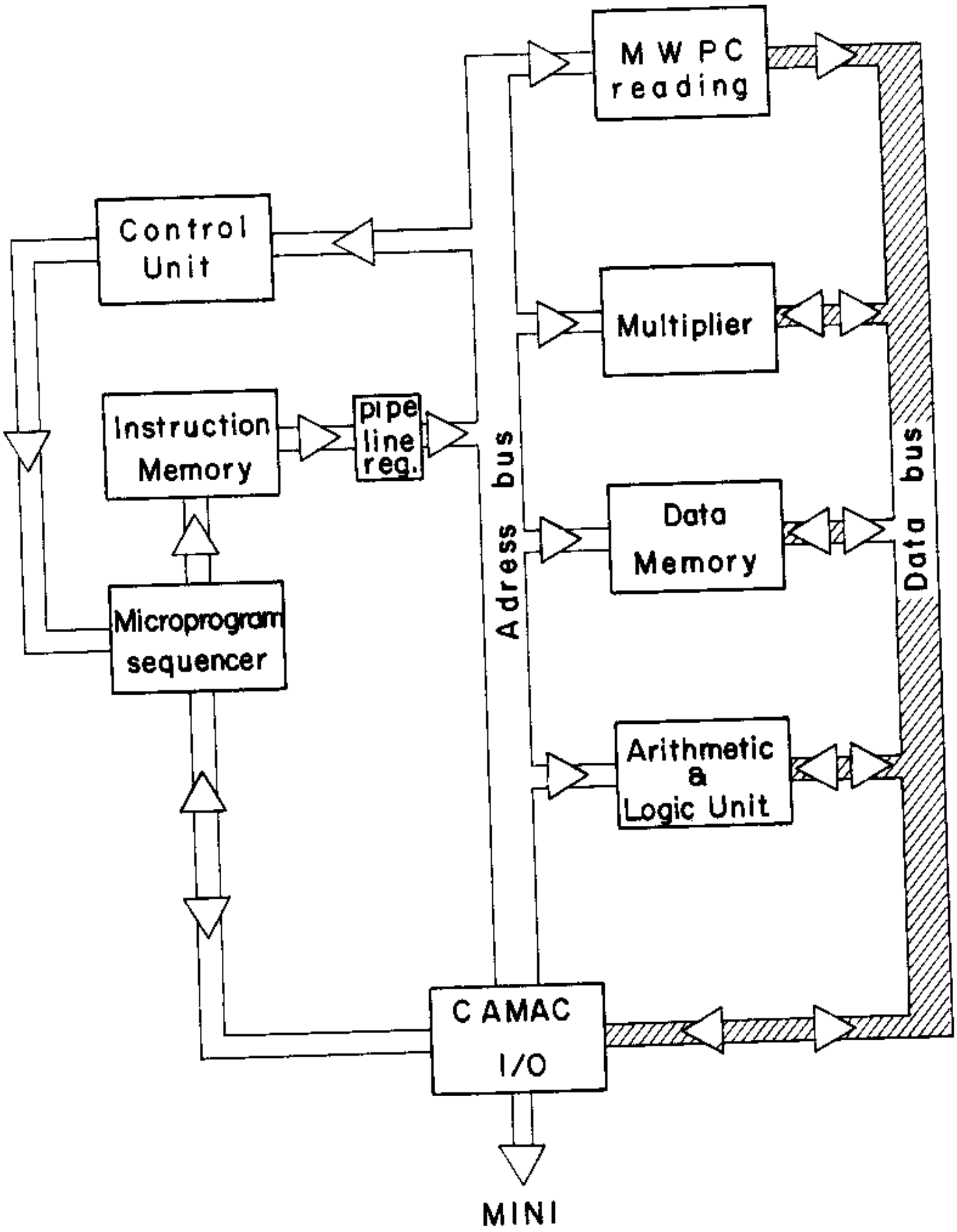

M W P C reading
Control Unit
Multiplier
Instruction Memory
pipe line reg.
Adress bus
Data bus
Data Memory
Microprogram sequencer
Arithmetic & Logic Unit
C AMAC I/O
MINI

Fig. 3

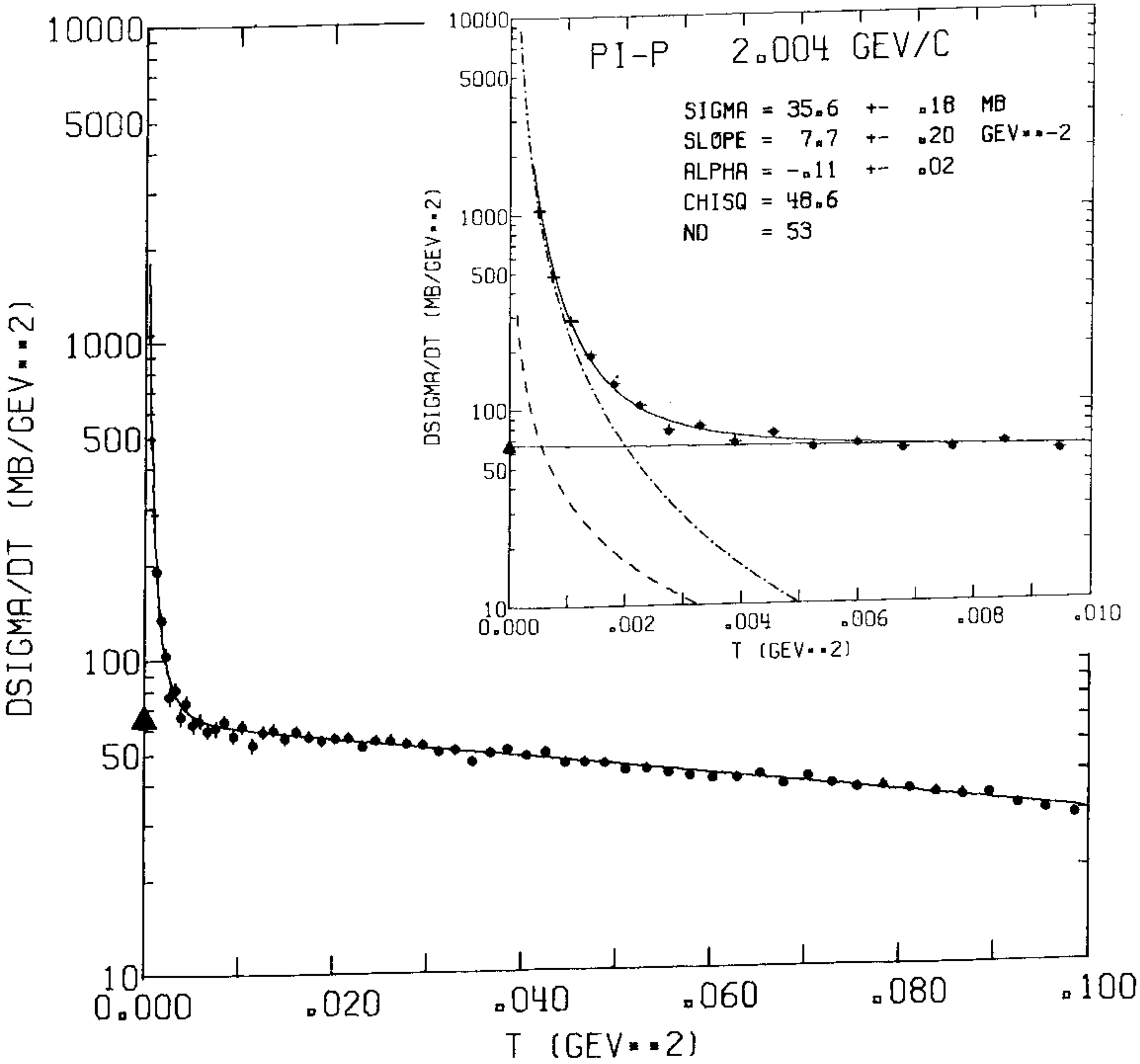

PI-P 2.004 GEV/C
SIGMA = 35.6 +- .18 MB
SLØPE = 7.7 +- .20 GEV**-2
ALPHA = -.11 +- .02
CHISQ = 48.6
ND = 53
DSIGMA/DT (MB/GEV**2)
T (GEV**2)
10000
5000
1000
500
100
50
10
0.000
.002
.004
.006
.008
.010
.020
.040
.060
.080
.100

Fig. 4

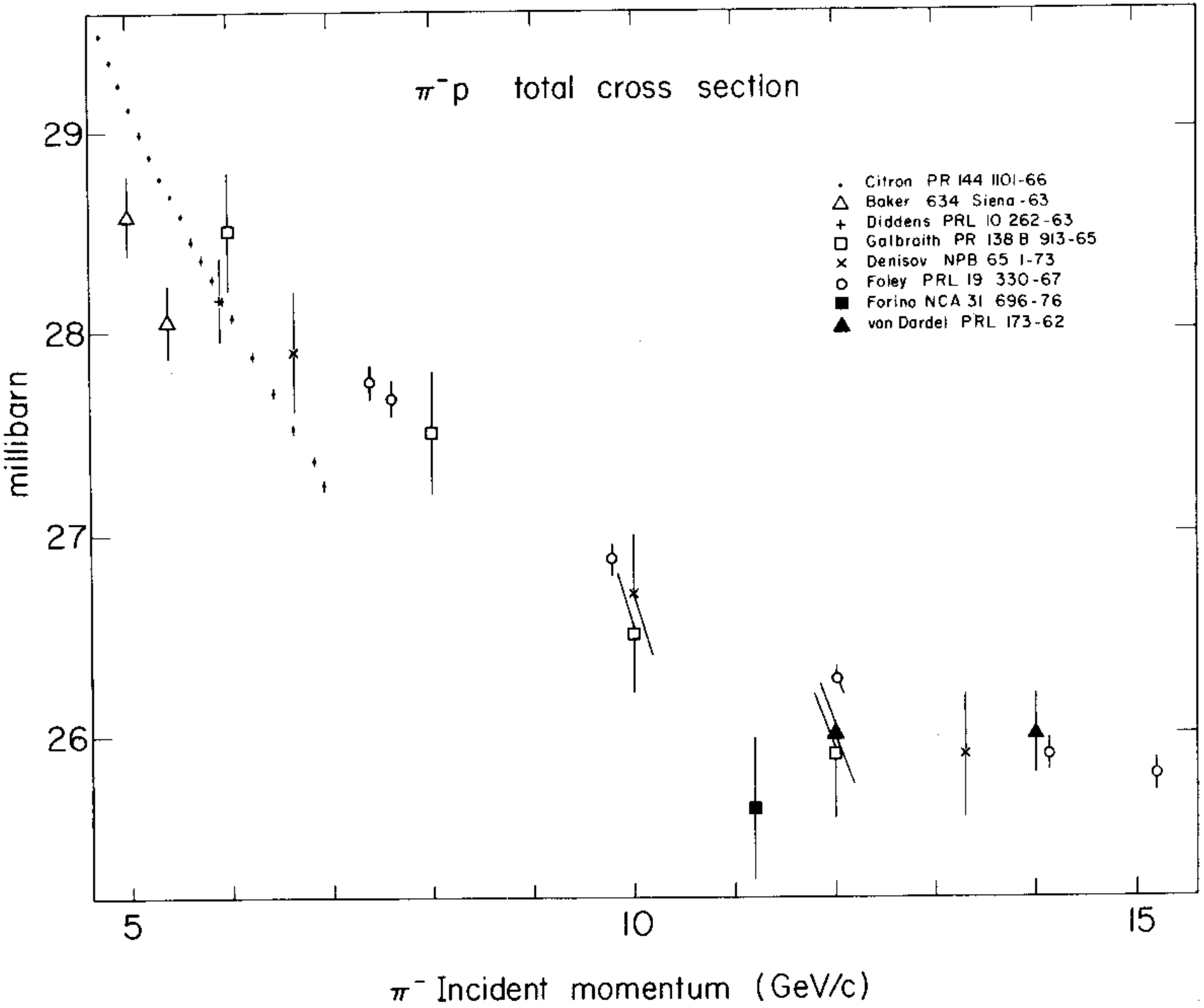

π⁻p total cross section
Citron PR 144 1101-66
Baker 634 Siena-63
Diddens PRL 10 262-63
Galbraith PR 138 B 913-65
Denisov NPB 65 1-73
Foley PRL 19 330-67
Forino NCA 31 696-76
von Dardel PRL 173-62
millibarn
29
28
27
26
5
10
15
π⁻ Incident momentum (GeV/c)

Fig. 5