A SPECTROMETER FOR MEASURING INELASTIC SECONDARIES
FROM 200 GeV/c, p-p COLLISIONS

T. O. White

August 17, 1968

One experiment which will no doubt be a part of the early experimental program of the 200-GeV machine will be aimed at a survey of inelastic production of secondary particles by protons to 200 GeV/c on hydrogen and heavy targets. In making a first approximation to the form which this experiment might take, it is instructive to explore in some detail the properties of a relatively cheap and simple spectrometer which can measure yields of long-lived secondaries over a wide range of longitudinal and transverse momenta.

General Layout

Figure 1 shows the layout of one of the simplest designs. The single-arm spectrometer is about 127 meters long. It employs two conventional 15-kG bending magnets, each 10 meters long, and a DISC counter system described below. The magnet system operates as in previous designs.[1] Particles emerging from the target at a desired angle and momentum are deflected to the vicinity of point P by M1. Then M2 bends the trajectory along the fixed spectrometer axis. This system accepts secondary momenta up to 180 GeV/c over the production angle range 0 to 20 mrad.

In the absence of a restoring septum, the primary beam is, of

course, deflected to various positions along an extended beam stop to

the rear of the apparatus. The closest approach of the primary beam

to the upstream end of the DISC counter is about 30 cm and occurs when

180 GeV/c positive secondaries are being analyzed at 0 mrad.

The DISC System

The DISC system envisioned consists of a scintillation counter

defining telescope ($S_1 \ldots S_4$ in Fig. 1), a quadrupole triplet to render

the secondary beam parallel, and two model "C" DISC counters[2] whose

specifications are given in Table I. The aperture of the system is about

10 cm. Each quadrupole can easily be less than one meter in length, and

the 10-meter length specified for each DISC counter can be reduced con-

siderably as more efficient photocathodes are developed. The use of

two DISC counters is advantageous since together they can measure each

other's efficiency and provide superb background rejection. The velocity

resolution of $\Delta\beta/\beta = 2 \times 10^{-6}$ for one counter is sufficient for π-K

separation at 180 GeV/c where $\beta\pi - \beta K = 3.5 \times 10^{-6}$ and the effect of

the spectrometer's finite momentum acceptance on this resolution is

negligible (see below).

Resolution

The intrinsic effective momentum resolution of the spectrometer

is determined principally by two components: (1) the resolution due to

secondary beam geometry and dispersion, and (2) the DISC counter

velocity resolution $\Delta\beta/\beta = 2 \times 10^{-6}$. Table II(a) gives $\Delta p_1/p$ due to

(1) as a function of production angle. It is typically a few percent and

can of course be reduced by replacing the defining telescope by hodo-

scopes, increasing the effective dispersion, etc. Qualitatively, the

effective resolution tends to be dominated by (1) under the following

conditions: (a) at high secondary momenta where $\Delta\beta$ brackets a wide

momentum band; (b) light particles where $\Delta\beta$ corresponds to a large

Δp even at low momenta; and (c) where production angles are smaller,

corresponding to a smaller beam-determined $\Delta p/p$. Some of this be-

havior is illustrated in Fig. 2 where the momentum bite Δp is shown

as a function of secondary momentum for π's, K's, and protons pro-

duced at 0 mrad. The dashed line indicated the effective resolution in

the case of protons under the assumption that the components (1) and

(2) are rms Gaussian spreads. Table II(b) contains Δp_2 due only to

the DISC counter velocity resolution for various particles and momenta

at angles of 0 and 20 mrad, and Table II(c) gives the final effective

resolution.

The angular resolution of the spectrometer is above 1 mrad and

the solid angle subtended is 8.2×10^{-7} sr.

Comments on the Primary Beam and Target

Although a detailed description of the primary beam is beyond the

scope of this note, a few comments must be made prior to rate estimates.

Let us make the following assumptions:

    (1) The momentum spread of the primary beam is $\lesssim$ 1%.

    (2) The angular divergence is ~ 0.1 mrad.

    (3) The apparent target diameter satisfies a relation (Ref. 2)

        which avoids erosion of the DISC acceptance:

$$\phi < F \, \delta\theta \, ,$$

        where ϕ is the target diameter, F is the focal length

        of the entrance quadrupole (~ 10^4 cm), and $\delta\theta$ is the

        angular aperture of the DISC counter (~ 10^{-4} rad minimum).

Assumptions (1) and (2) allow us to use Δp directly from Table

II(c) in calculating rates. Assumption (3) has several implications

worth noting: It allows an apparent target width of < 1 cm. Given that

the maximum angle from which the target is viewed is 20 mrad, the

length is then restricted to < 40 cm for an actual target diameter of

a few mm. And for a tiny, target-defining beam traversing ~ 40 cm

of hydrogen, somewhat less than 10% of the incident protons will

interact.

Rate Estimates

    T. G. Walker[3] has presented plots of secondary yields from

200-GeV p-p collisions as predicted in the model of Hagedorn and Ranft.[4]

Based upon these yields, counting rates in this spectrometer are given

in Table III.

As a way of quickly seeing over what ranges counting rates are "reasonable", assume that 10^8 protons interact in the target per machine pulse (i. e. a primary beam of ~ 10^9 protons/pulse), and that 10^3 machine pulses occur per hour. Then the rates per hour of various secondaries appear in Figs. 3-5. These results indicate that even a simple spectrometer like this one can test is a very definitive way present theories of particle production.

REFERENCES

[1] See, for example, Ratner et al., Phys. Rev. 166, 1353, (1968).

[2] O. Danielsson et al., CERN/EFCA 67/16, Vol. I, p. 391.

[3] T. G. Walker, NAL Summer Study Report B. 5-68-24, 1968.

[4] R. Hagedorn and B. Ranft, CERN/EFCA 67/16, Vol. I, p. 170.

Table I.   DISC Counter Specifications.

Length:	10 meters
Aperture Diameter:	10 cm
Cerenkov Angle:	20 mrad
Angular Acceptance:	1 mrad
$\Delta\beta/\beta$:	2×10^{-6}

Table II(a). $\Delta p/-$ Due to Geometry and Secondary Beam Dispersion Alone.

Production angle, mrad	0	5	10	16	20
$\Delta p/p$ (FW)	0.0208	0.0239	0.2080	0.0352	0.0426

Table II(b). Δp_2 in GeV/c Due Only
to DISC Counter Velocity Resolution.

Momentum, GeV/c	60	100	140	180
π	22.1	102	283	609
K	1.77	8.20	22.5	47.8
p	0.491	2.27	6.24	13.3

Table II(c). Final Effective Δp in GeV/c
of Spectrometer Assuming Δp_1, Δp_2 Are Gaussian Spreads.

Momentum GeV/c	60	100	140	180
π 0 mrad	1.25	2.08	2.91	3.74
π 20 mrad	2.54	4.26	5.96	7.67
K 0 mrad	1.02	2.02	2.89	3.74
K 20 mrad	1.46	3.78	5.76	7.57
p 0 mrad	0.457	1.54	2.64	3.60
p 20 mrad	0.482	2.01	4.31	6.64

Table III.   Yields Per Interacting Proton.
(All numbers to be multipled by 10^{-7}.)

Momentum GeV/c		60	100	140	180
π^+	0 mrad	203	220	72	0.62
	20 mrad	3.2	0.035		
π^-	0 mrad	72	37.5	9.5	0.266
	20 mrad	1.45	0.167		
K^+	0 mrad	25	23	5.9	0.012
	20 mrad	0.475	0.0031		
K^-	0 mrad	3.75	1.07	0.165	0.0018
	20 mrad	0.237	0.0031		
p	0 mrad	43.4	655	2800	6240
	20 mrad	0.6300	0.0558		
$\bar{p}$	0 mrad	0.289	0.151	0.0162	
	20 mrad	0.0197	0.00049		

FIGURE CAPTIONS

Fig. 1. Single-arm spectrometer for inelastic p-p scattering.

Fig. 2. Contributions to momentum resolution.

Fig. 3. Pion counting rates at 0 and 20 mrad as a function of momentum.

Fig. 4. Kaon counting rates at 0 and 20 mrad as a function of momentum.

Fig. 5. Proton and antiproton counting rates at 0 and 20 mrad as a

function of momentum.
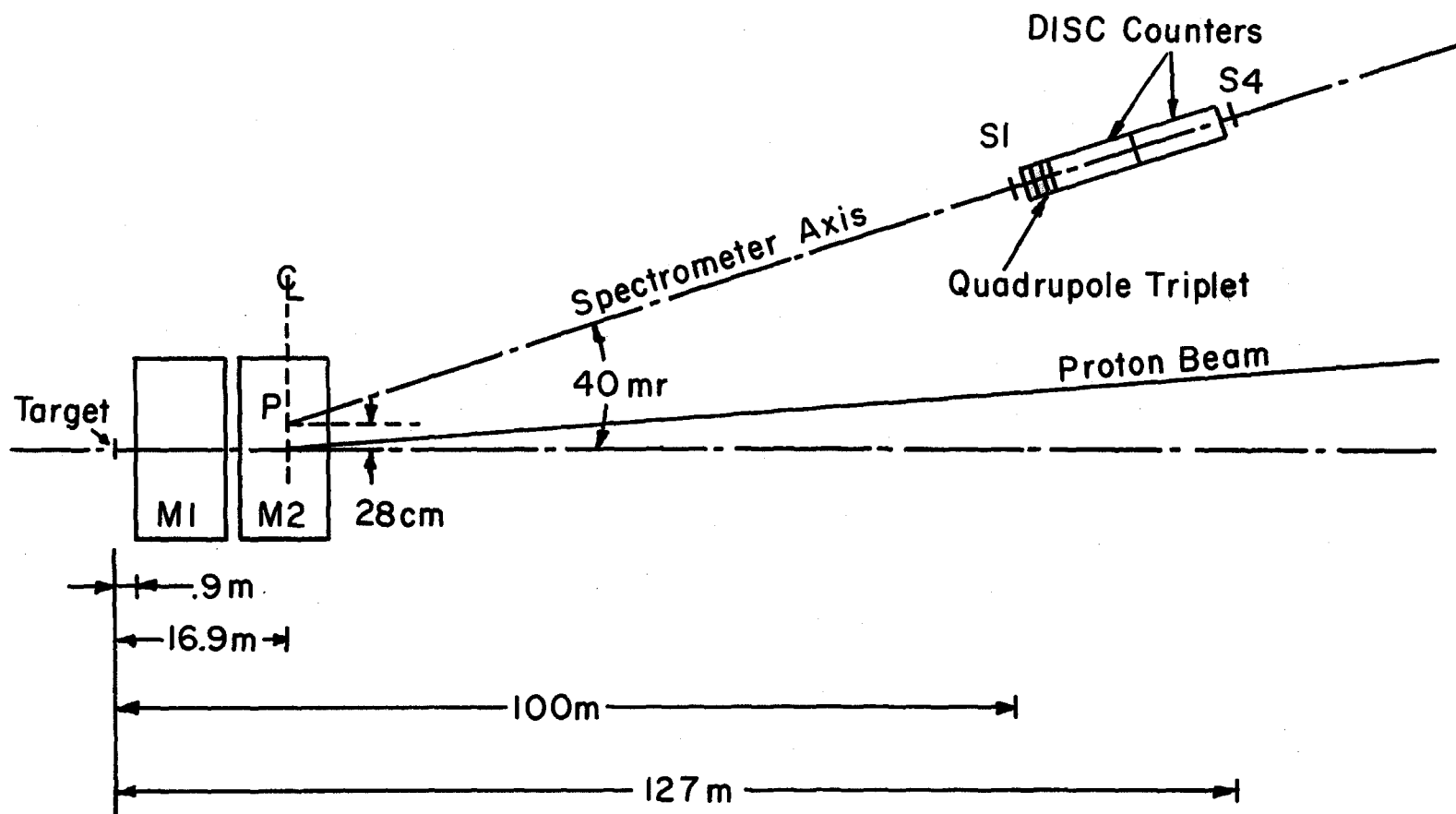
(Drawing not to Scale)

Fig. 1
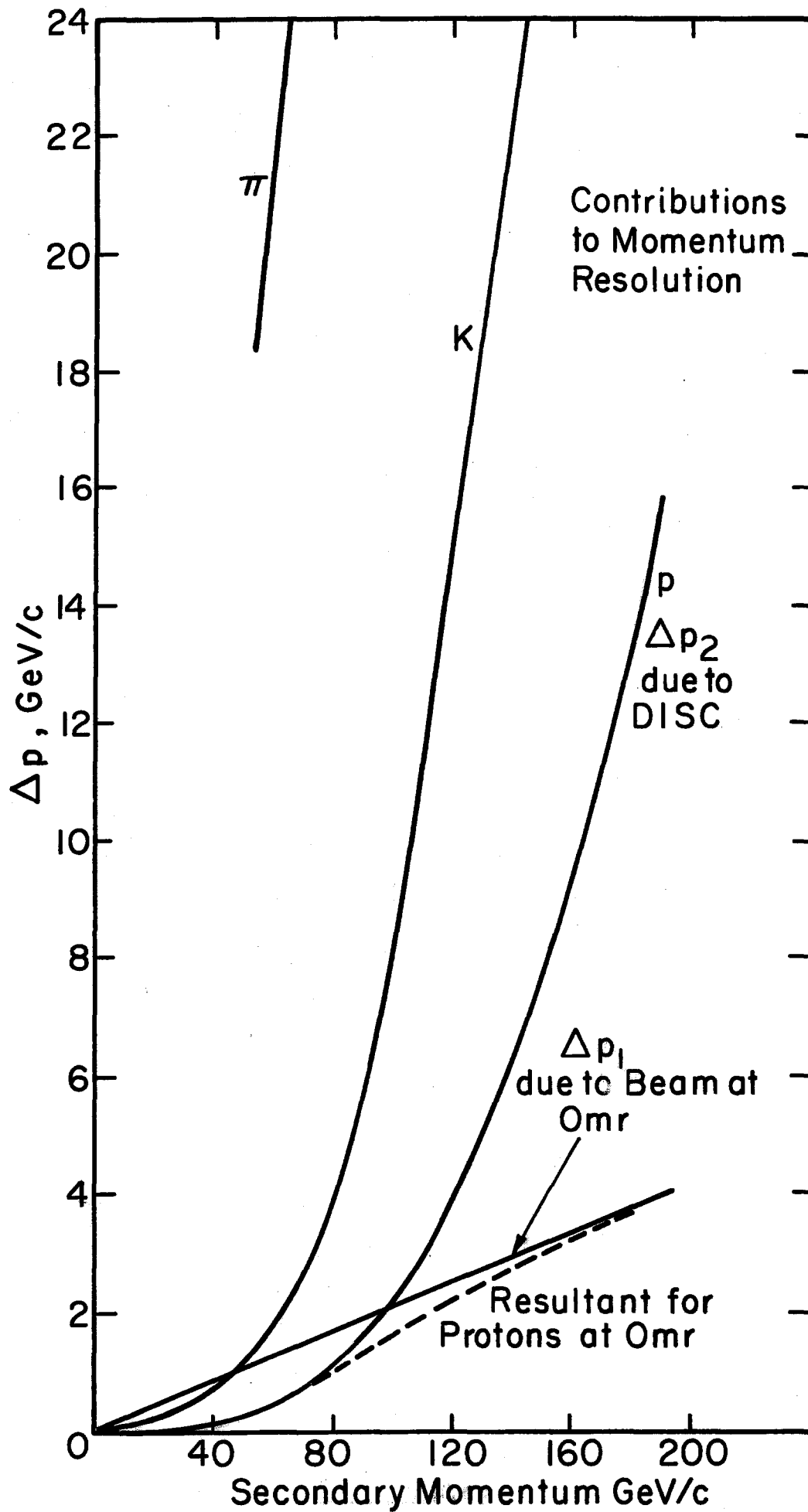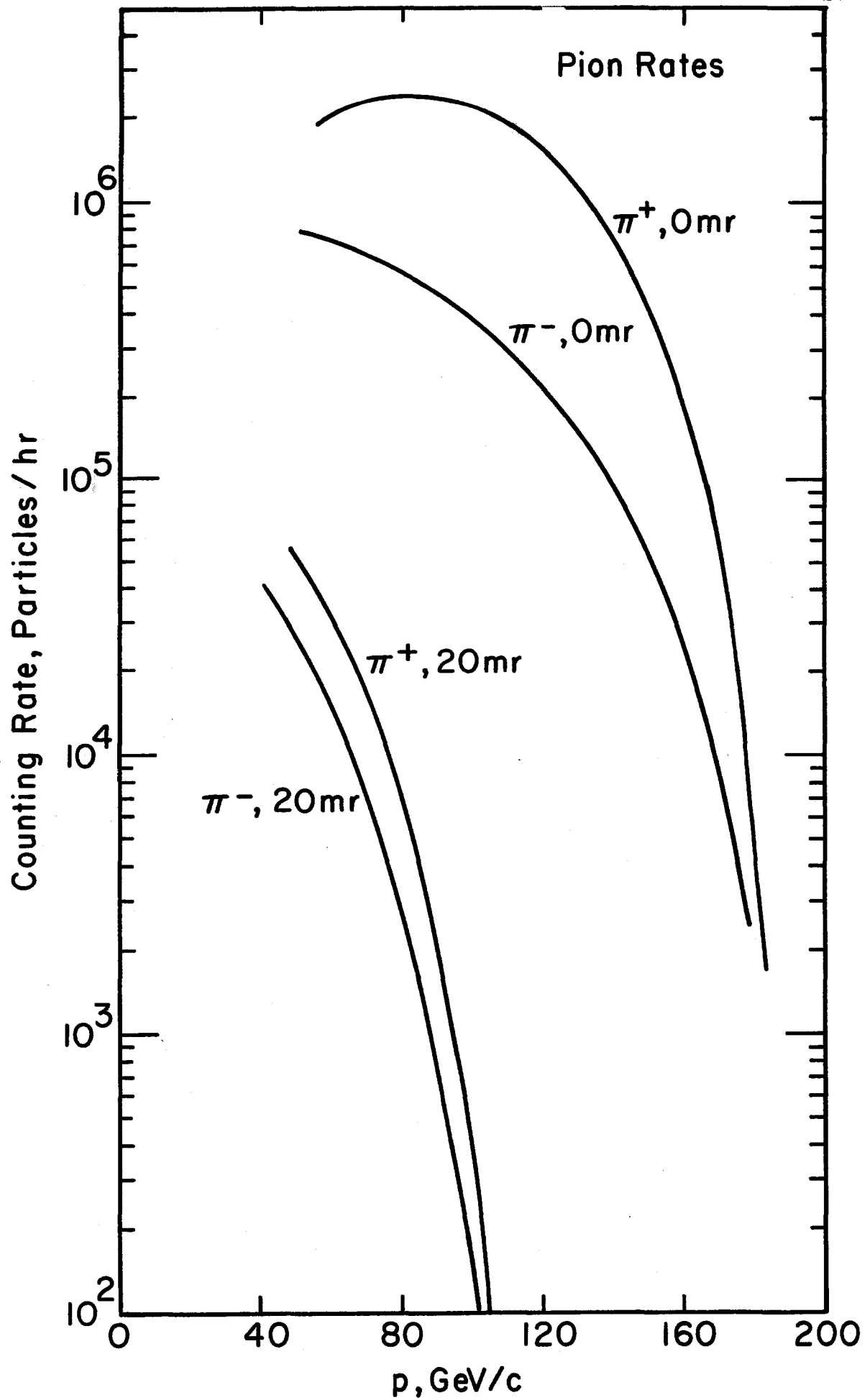
Fig. 2

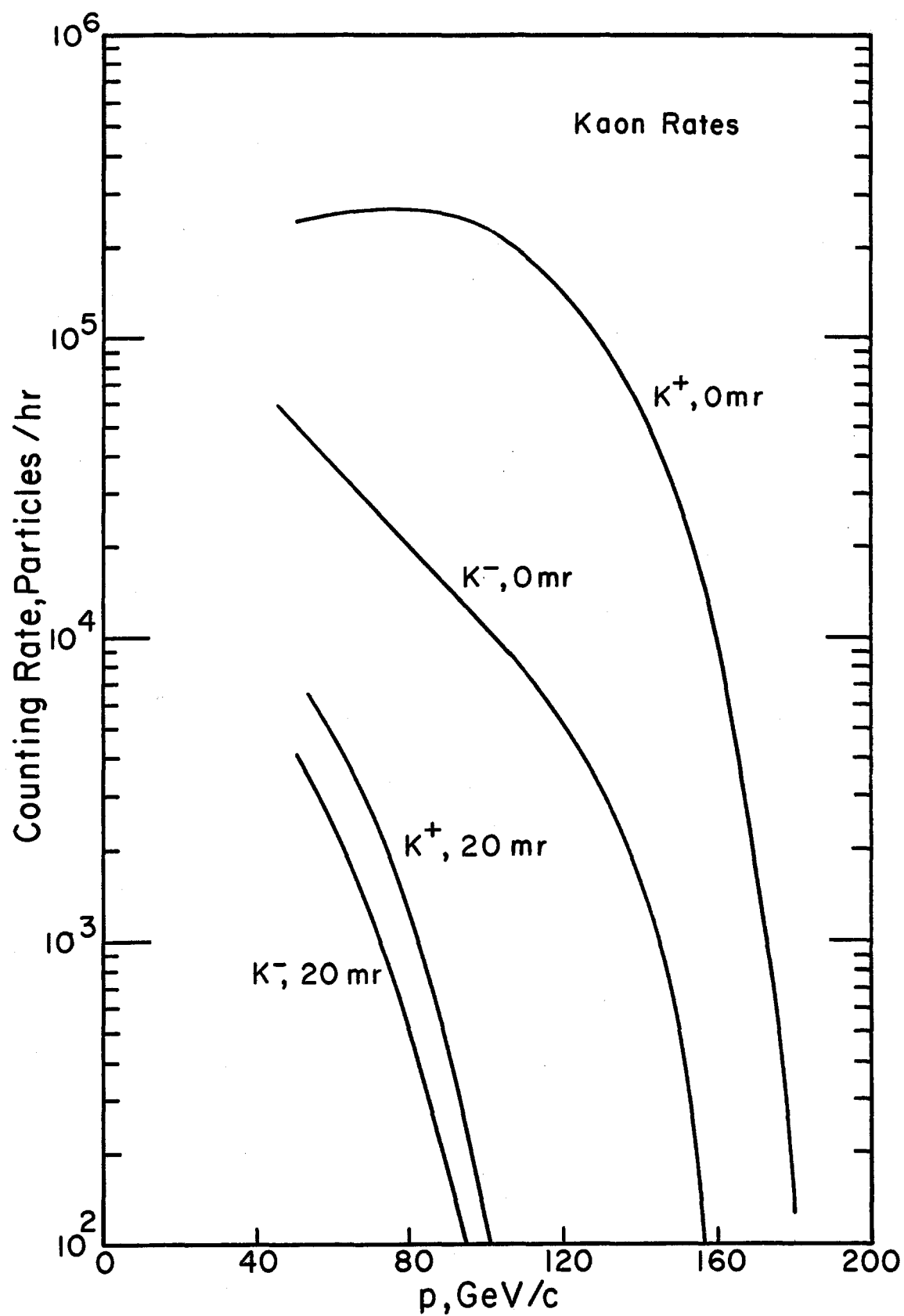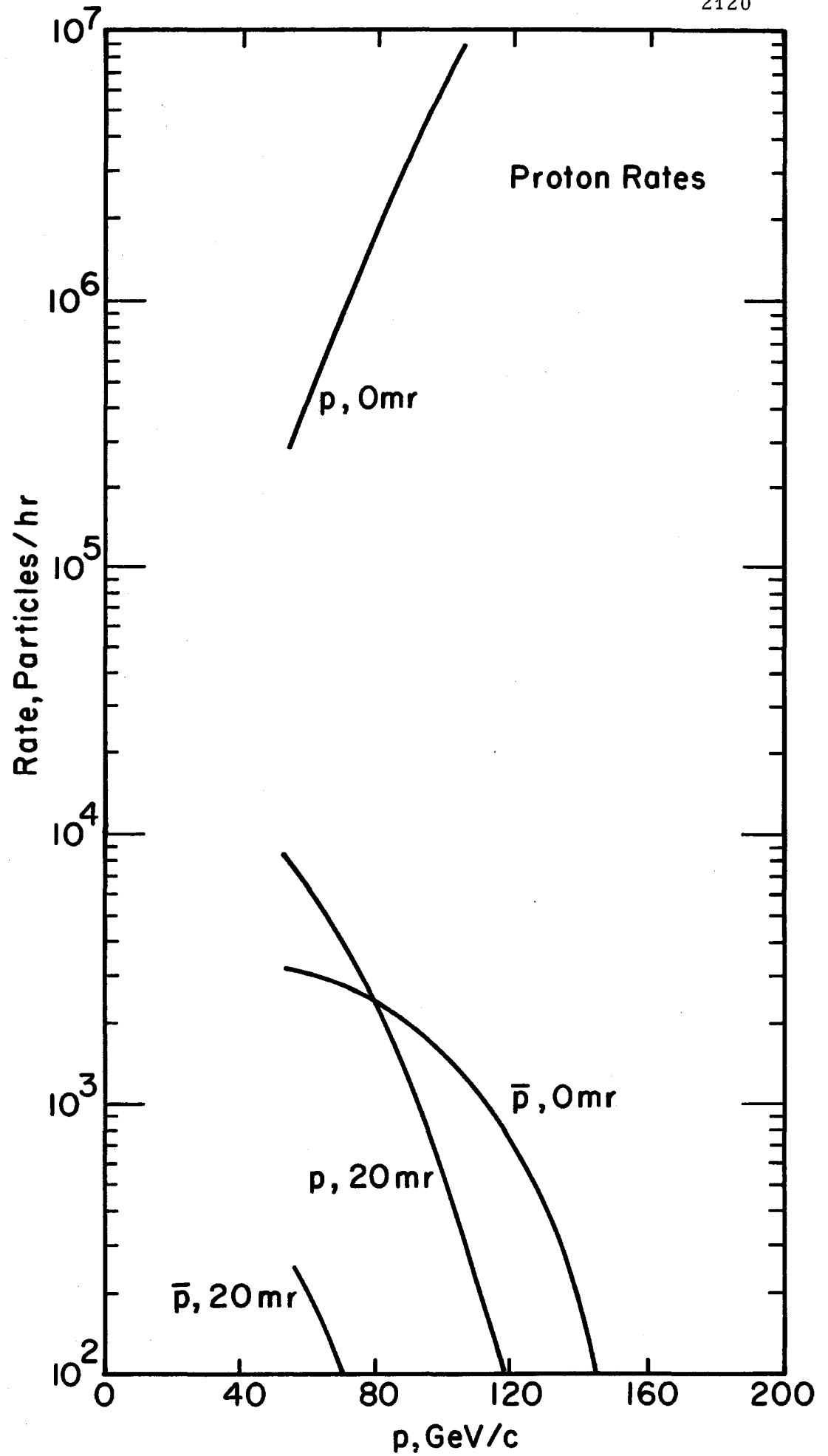Fig. 3

Fig. 4

Proton Rates

p, Omr

$\bar{p}$, Omr

p, 20 mr

$\bar{p}$, 20 mr

Rate, Particles / hr

p, GeV/c

Fig. 5