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PROPOSAL TO MEASURE πp ELASTIC SCATTERING AT LARGE ANGLES

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1. Introduction

We propose to measure 200 GeV/c large angle πp elastic scattering to cross sections of less than 5×10^{-36} cm^2/(GeV/c)^2, which should correspond to $|t|$ values of greater than 8(GeV/c)^2. Since previous 100 to 200 GeV/c large angle data extend only to $-t \simeq 2$,[1] this will be an appropriate second generation experiment. In addition, we will obtain $K^{\pm}p$ and $\bar{p}p$ data down to cross sections of 10^{-34} cm^2/(GeV/c)^2. This will enable comparisons to be made among the scattering of these various particles, together with a comparison with the more extensive pp scattering data.[2]

The experiment uses much of the equipment currently used by E290 (Arizona-Fermilab), and is designed to use an incident beam flux between 5×10^7 and 5×10^8 pions per accelerator cycle. Although current Meson Lab plans are incomplete, it is possible that upgrading in that lab could make the experiment feasible in either the M6 or the M1 beam lines.

2. Experimental Method

The layout is shown in Fig. 1 (the recoil arm) and Fig. 2 (the forward arm); it is a two-arm magnetic spectrometer system. The recoil arm shows the 72D18 currently used in E290; a magnet with similar horizontal and vertical aperture (72" x 12") but greater $\int Bdl$ would enable smaller detectors to be used, giving a reduced trigger rate and better signal to background ratios. The forward arm requires two BM109 magnets, as does E290.

The proportional chambers and scintillation counters are those used in E290, with some modifications; a 1 meter liquid hydrogen target is used, which could be the E290 target appropriately modified.

Just as in the pp elastic scattering experiment, E177[2] and the polarized target elastic scattering experiment E61,[3] no detectors are used (or required) in the incident beam, in order to utilize its high intensity. Minority particle scattering is detected using two threshold Cerenkov counters in the forward arm to differentiate between the particle types. These counters will be calibrated using existing Cerenkov counters in the incident beam at reduced beam intensity.

We will measure scattering angle and momentum for both outgoing particles ($\Delta p/p$ in the recoil arm, for example, assuming use of the 72D18 magnet, is ±5% at $-t = 6$). This gives us more constraints in the analysis than for previous experiments in this energy range. We lose some information by the lack of detectors in the incident beam, but we will show later that this does not give rise to excessive backgrounds.

Our trigger is very selective. In the forward arm, coincidences are made between a counter in hodoscope α and a corresponding counter in hodoscope β, cutting down the momentum acceptance for triggers in this arm. An appropriate matrix of coincidences is made between the forward (α, β) hodoscopes and the recoil hodoscope to trigger preferentially on elastic events. Such selective triggering has been used in similar large angle elastic scattering experiments at the AGS.[4,5,6]

3. Event Rate

The event rate is calculated using the following assumptions:

(i) A 1 meter liquid hydrogen target.

(ii) A beam intensity of 5×10^7 pions/accelerator cycle.

(iii) A run of 350 hours at each polarity.

(iv) The use of proportional wire chambers and a tight triggering scheme, so that readout dead time is small.

A target length of 1 meter gives the number of target protons = $N_p = 4.2 \times 10^{24}$ cm^{-2}.

With 5×10^7 pions/cycle, 12 second repetition rate and a run of 350 hours, total number of pions = $N_\pi = 5.3 \times 10^{12}$.

The number of counts N_B in a bin Δt $(GeV/c)^2$ wide, with azimuthal acceptance $\Delta\phi/2\pi$, for a cross section of $d\sigma/dt$ $cm^2/(GeV/c)^2$ is

$$N_B = N_\pi N_p \frac{d\sigma}{dt} \Delta t \frac{\Delta\phi}{2\pi}$$

For $\Delta t = 1(GeV/c)^2$ and our typical $\Delta\phi/2\pi$ of 0.05, we expect 6 events for a cross section of 5×10^{-36} $cm^2/(GeV/c)^2$.

We show later that we can take beam intensities as high as 5×10^8/pulse. This intensity would allow cross sections as low as 5×10^{-37} $cm^2/(GeV/c)^2$ to be measured for π^-.

Minority particles $K^\pm$ and $\bar{p}$ are ~1% -10% of the beam, giving cross section limits 10 to 100 times larger than for pions.

4. Counting Rates in Detectors

We show that the particle flux through the PWC's between the target and analyzing magnets in the two arms will not be excessive even at a beam intensity of 5×10^8 per pulse. Rates in detectors after the magnets will be lower than those before the magnets.

a) Recoil Arm

We base the calculation on the following assumptions

(i) πp inelastic scattering at 200 GeV/c is not very different from that of 200 GeV/c pp scattering.

(ii) We use the extensive 19 and 24 GeV/c pp inelastic data,[7] and scale $E/p^2 \frac{d^2\sigma}{dp d\Omega}$ as a function of x and $p_\perp$.

Use of (ii) above can be checked by calculating the rate in a set of monitor counters in the pp experiment E177. In that experiment, the counting rate in a 3 counter telescope ($\Delta\Omega$ = 4×10^{-6} sr) at a laboratory angle of 33^{o} was $6.9/10^{8}$ protons, whereas the calculation gives 3.5 counts/10^{8} protons. Accordingly we increase our calculated values by a factor of 2 to allow for this discrepancy.

The result of the calculation for our PWC in front of the recoil magnet is that the total counting rate should be 1.7×10^{6} for 5×10^{8} incident beam intensity.

b) Forward Arm

We calculate counting rates as for the recoil arm, with the input data augmented by 200 GeV/c inelastic pp data.[8]

The result is that for a detector covering the range $2 < |t| < 10$, and with our azimuthal acceptance, the counting rate will be 1.8×10^{6} for 5×10^{8} incident beam particles.

c) Conclusion

For incident intensities up to 5×10^{8} per pulse, the rates in detectors before the analyzing magnets will be less than 2×10^{6}/pulse, a rate that, from E290, we know our detectors can comfortably handle. In the case of the forward arm, rates will be higher between $1 < | t | < 2$, so we will cover that region in a short lower intensity run before moving the detectors to cover the $2 < | t | < 10$ region.

We thus conclude that this experiment can operate in beam intensities up to 5×10^{8} per pulse.

5. Backgrounds

Predicting inelastic backgrounds in two-arm elastic scattering experiments is notoriously difficult. A more reliable method for this experiment is to make a comparison with the similar experiment E177[2] on large angle pp scattering.

This experiment will have an incident beam with larger angular divergence, momentum spread and spot size than E177, but unlike E177, we will measure the directions of both scattered and recoil particles before the two analyzing magnets. The momentum resolutions in the two experiments are quite similar.

We assume the conservative beam properties of ±2% $\Delta p/p$, ±0.5 mr angular divergence, and ±0.5 cm spot size.

Forward Arm

An uncertainty in beam momentum of ±2% will increase the uncertainty in missing mass calculated from the forward pion by a factor of 4 over that caused by the momentum resolution of the arm alone (± 1/2%). In E177, the momentum resolution of the forward arm was ±1.5% (see Fig. 3). The net effect is that our missing mass resolution is 4/3 that of E177, increasing our background by 4/3 over that of E177. Beam divergence of ±0.5 mr has a negligible effect on the missing mass.

Recoil Arm

The effects of beam divergence and incident momentum uncertainty on the missing mass calculated from the recoil arm are much less than the effect of the momentum resolution of that arm. Our momentum resolution is 15% better than that of E177, giving a corresponding reduction in background by that amount due to the recoil arm.

Coplanarity

The coplanarity resolution is dominated by the uncertainty in the forward azimuthal scattering angle due to lack of knowledge of the incident beam direction. Using a beam divergence of 0.5 mr gives a coplanarity resolution at $-t = 6$ of 40 mr, to be compared to E177's 10 mr. Thus we expect an increase in background over that of E177 of about a factor of 4 due to this effect.

Beam Spot Size

The event interaction point in the hydrogen target can be determined using the PWC's to an accuracy of ~1/8" transverse to the beam direction. This is about the same size as the proton beam used in E177, so there should not be an increase in background due to this effect.

Conclusion

We have determined that our background should be about $0.85 \times 4 \times 4/3 = 4.5$ times that of E177. However in that experiment (see Fig. 3) the inelastic background even at $|t| \sim 11$ was less than 3%, and the percentage decreased at lower momentum transfers. Thus our background should always be less than 14% of the signal. (Even if the background were larger than this, it will be measured with good statistics and can be subtracted to accurately obtain the signal.)

6. Resolution in t

The t resolution determines the narrowness of structures that can be observed in the angular distribution. In this experiment it is obtained from the scattering angle of the recoil particle; at $-t = 6$, for example, Δt is 0.1 $(GeV/c)^2$, very similar to that of E177.

7. Comparison with Previous Data

Figure 4 shows existing data at 23[5] and 200 GeV/c[1] for $\pi^- p$ elastic scattering, as well as 200 GeV/c pp data[2]; our expected sensitivities at 200 GeV/c for two incident beam fluxes are shown. If the differential cross section at 200 GeV/c is similar to that for pp scattering, we should be able to measure beyond $-t = 8$ for πp at 5×10^7 pions/pulse, and to $-t \simeq 10$ at 5×10^8 pions/pulse. For kaons and antiprotons, we would expect to measure to $-t \gtrsim 5$, an appreciable improvement on existing data.[1]

8. Physics

There exist many models for high energy, large angle proton-proton elastic scattering, stimulated by the existence of data from the ISR and Fermilab. Examples are constituent scattering models,[9] eikonal models,[10] quark-glue hadron models,[11] pomeron models,[12] and many others, all of which fit the data to a limited extent. In addition there are several parametrizations of the data.[13,14]

There has been much less theoretical work on large angle meson-proton elastic scattering, possibly because of the absence of comparable data. However, many of the models for proton-proton scattering could be modified for the meson-proton case, and meson-proton experimental data should be useful in differentiating between the models. Among specific predictions are that large angle meson-proton scattering will be less energy dependent than proton-proton scattering,[15] and that new dips will appear in the angular distributions.[16] Many constituent models predict larger cross sections than we have been assuming; a comparison of large t pp and πp scattering could give information on the extra quark involved in the pp case.[17]

Aside from comparisons with detailed theoretical models, there are a number of empirical questions that can be answered by the data.

(i) Do new diffraction-type phenomena appear at high energies? In pp elastic scattering, the $|t| = 1.4$ dip is not present at 100 GeV/c, but appears in 200 GeV/c data.[1] Does similar behavior occur in the meson-proton case?

(ii) The $\pi^- p$ data at 23 GeV/c has an (unexplained) abrupt change of slope at $-t = 3$; is this still present at 200 GeV/c? (We observe also in large angle pp scattering at ISR energies that the slope at $-t \simeq 5$ is appreciably less than at smaller $|t|$ values).

(iii) All measured K and π meson-proton cross sections appear to be equal around $-t = 1$ with no momentum dependence between 14 and 200 GeV/c[1,6] - see Fig.

5. This says that all meson-proton collisions behave similarly at small impact parameters, whereas they do not do so at large impact parameters (near $t \simeq 0$). Is this equality fortuitous, or does it continue to be true at even larger values of $-t$?

9. Equipment Required from Fermilab

All of the equipment currently used in E290 will be used in this experiment. Additional needs are as follows:

(i) If the 72D18 is used as the recoil magnet, a current of ~1200 amps will be needed (E290 uses ~600 amps).

(ii) Some modifications of the E290 PWC's and their stands will be required to fit the geometry of this experiment.

(iii) We will need a 100' threshold Cerenkov counter similar to that used in E61.

(iv) A modest amount of additional PREP equipment will be needed.

(v) A 1 meter liquid hydrogen target with appropriate windows is required. This might be the E290 target suitably modified.

10. Running Time

We will need 700 hours of running time to make measurements for both beam polarities to the accuracy noted earlier. In addition, 300 hours of set up time will be required.

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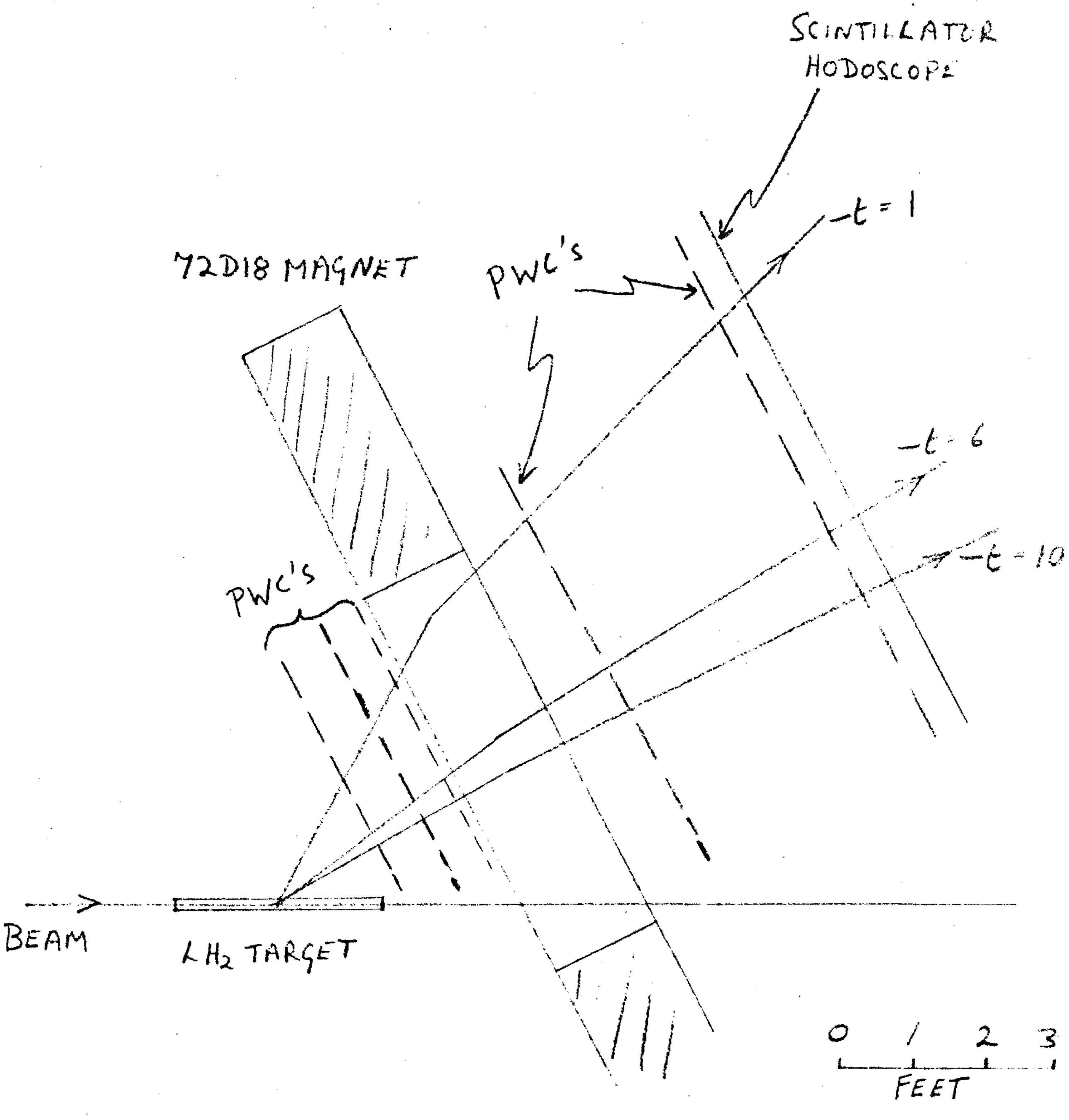
FIGURE 1.



SCINTILLATOR HODOSCOPE
-t = 1
72D18 MAGNET
PWC's
-t = 6
-t = 10
PWC's
BEAM
LH2 TARGET
0 1 2 3
FEET

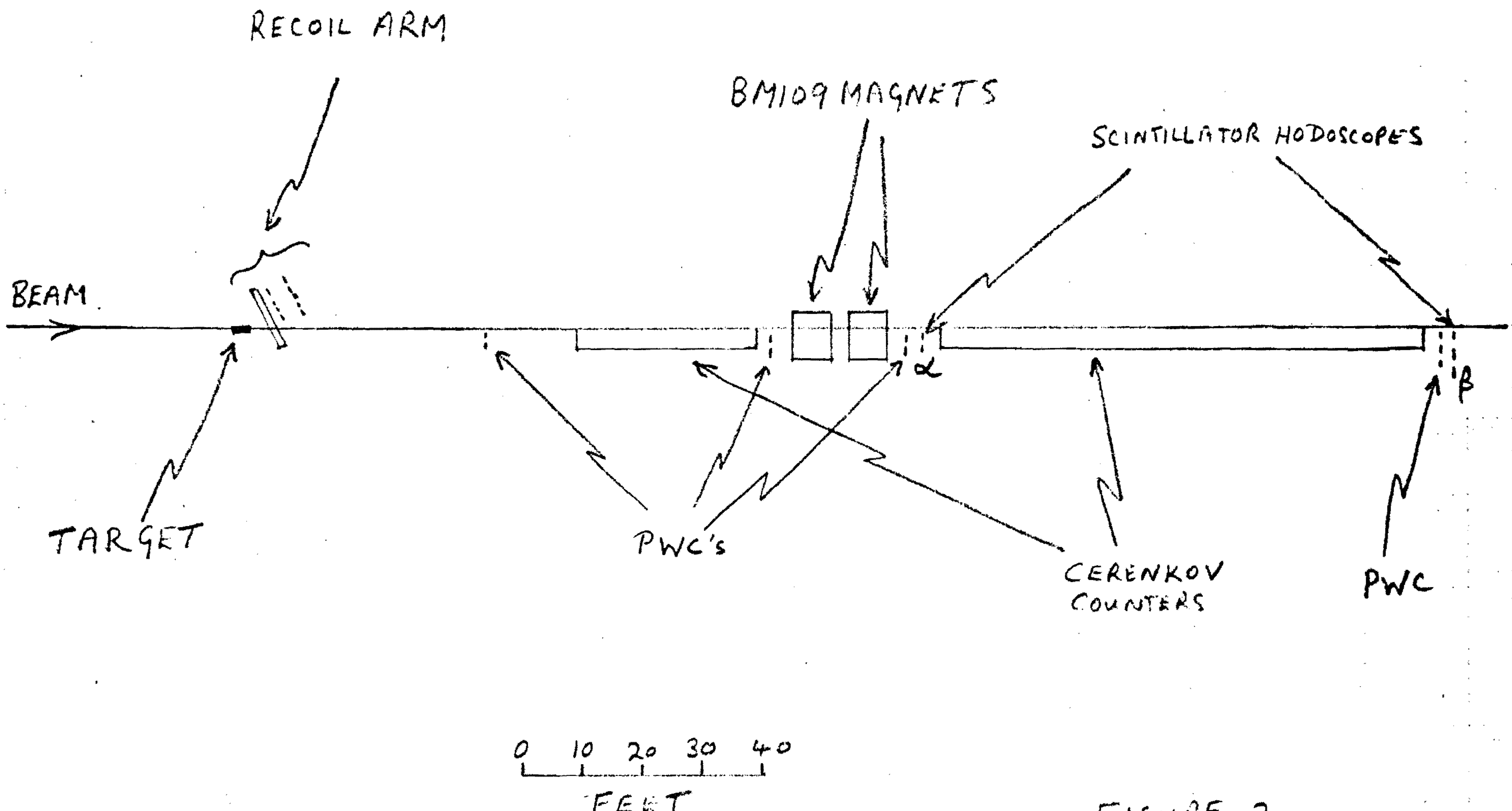

RECOIL ARM
BM109 MAGNETS
SCINTILLATOR HODOSCOPES
BEAM
α
β
TARGET
PWC's
CERENKOV COUNTERS
PWC
0 10 20 30 40
FEET

FIGURE 2.

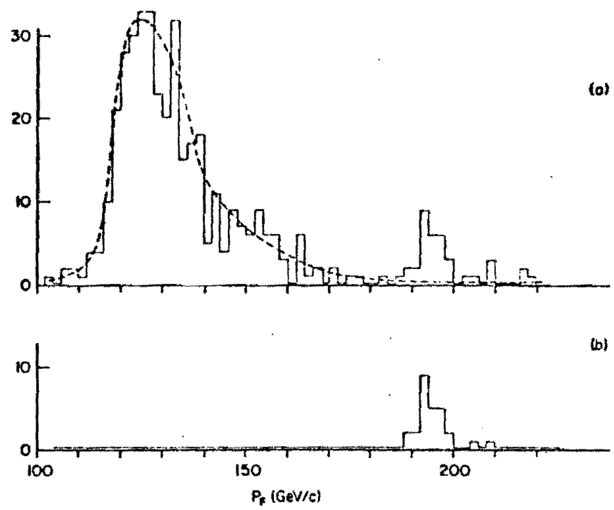
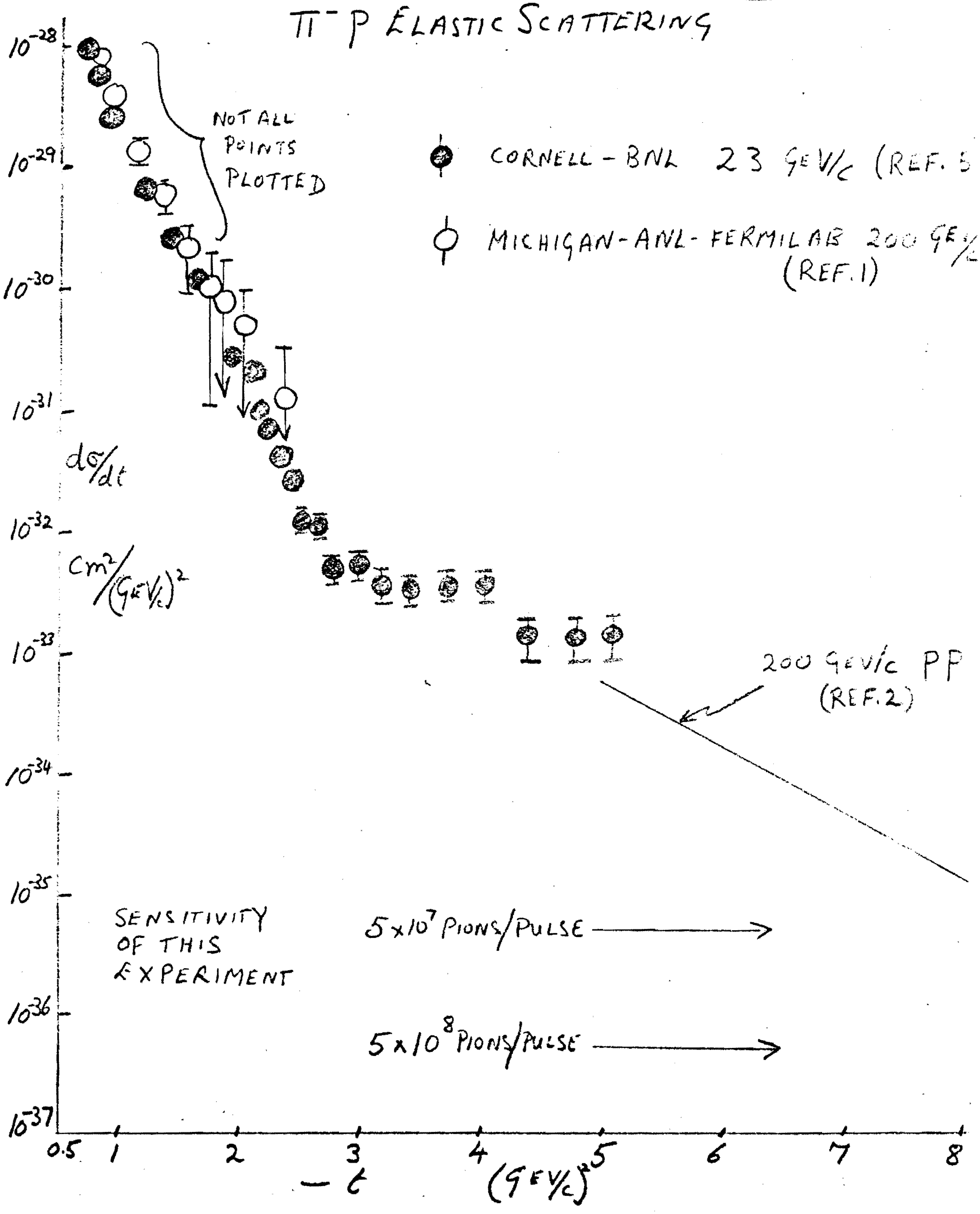


FIG. 2. (a) Momentum distribution in forward arm for events with $10.7 < |t| < 11.5$ GeV^2. Only the target height cut has been made. Dashed line is an "eyeball" extrapolation of inelastic background. (b) Same as (a) except that coplanarity, Δt, and recoil missing-mass cuts have been made.

DISTRIBUTIONS OBTAINED IN 200 GeV/c P P SCATTERING. (FROM REF. 2)

FIGURE 3.

FIGURE 4.



π⁻ P ELASTIC SCATTERING
NOT ALL POINTS PLOTTED
CORNELL - BNL 23 GeV/c (REF. 3
MICHIGAN-ANL-FERMILAB 200 GeV/c (REF. 1)
200 GeV/c PP (REF. 2)
SENSITIVITY OF THIS EXPERIMENT
5×10^7 PIONS/PULSE
5×10^8 PIONS/PULSE
dσ/dt cm²/(GeV/c)²
10^-28
10^-29
10^-30
10^-31
10^-32
10^-33
10^-34
10^-35
10^-36
10^-37
0.5
1
2
3
4
5
6
7
8
-t (GeV/c)²

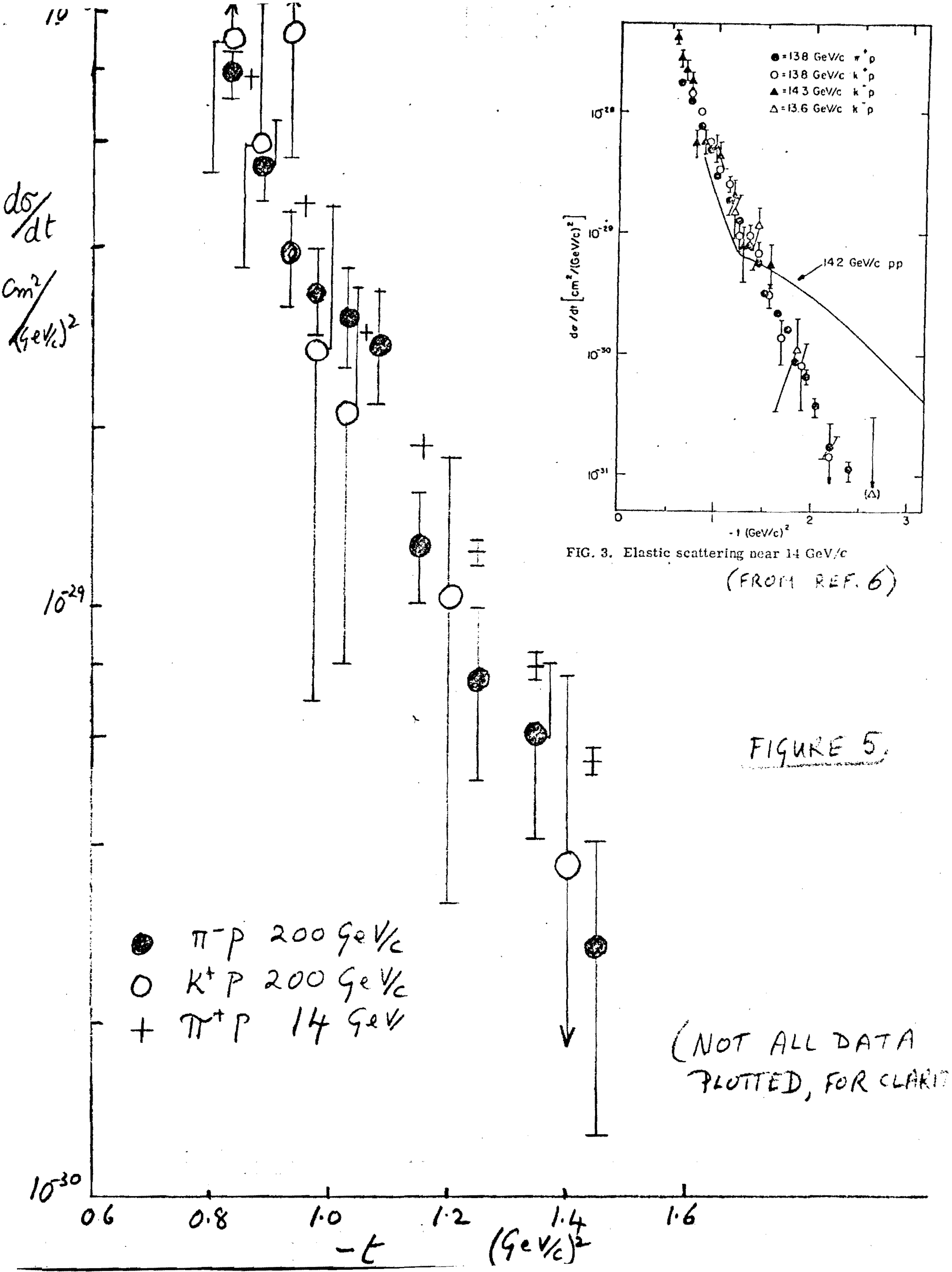


FIG. 3. Elastic scattering near 14 GeV/c

(FROM REF. 6)

FIGURE 5.