ELASTIC AND INELASTIC SCATTERING EXPERIMENTS WITH A SINGLE-ARM WIRE-PLANE SPECTROMETER

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ABSTRACT

This report describes experiments using a single-arm wire-plane spectrometer system to study elastic scattering and inelastic isobar production at 100 GeV/c, with either a secondary beam or the full intensity extracted proton beam.

I. INTRODUCTION

Although single-arm spectrometer experiments of this type have worked well up to 20 GeV/c, continuing the method into the 100 GeV/c region pushes present experimental techniques rather hard, as pointed out by T. G. Walker in last summer's study.[1] Nevertheless, since this approach has given data unattainable by other methods, its seems wise to carry it to as high an energy as possible.

II. RESOLUTION REQUIREMENTS

For the reaction

$$A\,(p_0, 0) + N \rightarrow A\,(p, \theta) + x\,,$$

the elastic or inelastic scattering of A on a nucleon N, the dependence of the missing mass M_x on the momentum and angle of A is

$$\frac{\partial M_x}{\partial p} = \frac{M_N}{M_x}\,;\ \frac{\partial M_x}{\partial \theta} = -\frac{p_0^2\theta}{M_x}\,.$$

To get a final mass resolution $\Delta M_x = \pm 50$ MeV, giving good elastic-inelastic separation, and a reasonable isobar mass measurement, individual sources of error should be held to $\sim \pm 25$ MeV. So $\Delta p = \pm 25$ MeV/c for both the incident and scattered high momentum beam particles, or at 100 GeV/c, $\Delta p/p = \pm 0.025\%$. The dependence of M_x on angle is important only at the larger momentum transfers. At 100 GeV/c, and $t = 4$ GeV/c^2, $p_\perp \simeq 2$ GeV/c ($\theta = 20$ mrad), $\Delta M_x/\Delta\theta \simeq 200$ GeV/rad or 200 MeV per milliradian. So for $\Delta M_x = \pm 25$ MeV, $\Delta\theta = \pm 0.12$ mrad, again, both on the incident and scattered beam particles.

III. SCATTERING EXPERIMENT USING THE SECONDARY BEAM

A. Beam Resolution Requirements

The dispersion and emittance being designed for the 2.5 mrad high precision unseparated beam in area 2, 4 cm/1% and 1 mrad·mm, can satisfy the above requirements. With a 1 mm proton target, a 2 mm momentum slit, and a horizontal magnification of 2, we find $\Delta p/p = \pm 0.025\%$. To limit $\Delta\theta$ to ± 0.12 mrad, the final image must be magnified to 4 mm [for $t = 4\ (\mathrm{GeV/c})^2$ scattering; a higher magnification is needed for larger momentum transfers]. The required momentum and angular resolution are thus directly obtainable in the beam without a counter hodoscope, permitting the use of a very high intensity diffracted proton beam.

B. Spectrometer Parameters

The momentum resolution for a magnet wire-plane system is

$$\frac{\Delta p}{p} = \frac{\Delta\theta}{\theta_{\mathrm{deflection}}},$$

with $\Delta\theta = \Delta x/d$, Δx the track measurement error and d the wire-plane separation before or after the magnet. So

$$\frac{\Delta p}{p} \propto \frac{1}{d\theta_{\mathrm{deflected}}} \propto \frac{1}{d\int B\,d\ell},$$

for a given measurement error Δx. Some curves are given by Walker.[1] To minimize $\int B\,d\ell$, d can be increased until multiple scattering becomes a problem. If one allows 2 g of H_2 equivalent for all multiple-scattering sources, chambers, any counters, etc., the multiple scattering is

$$\Delta\theta_{\mathrm{mrad}} = \frac{15}{p}\sqrt{t/t_{\mathrm{rad}}}\ \mathrm{mrad} = \frac{15}{100}\sqrt{\frac{2}{85}} = 0.02\ \mathrm{mrad}.$$

Allowing $\Delta\theta$ from measurement error to be of this order, say 0.025 mrad

$$\theta_{\mathrm{defl.}} = \frac{\Delta\theta}{\Delta p/p} = 0.025\times 10^{-3}/0.025\times 10^{-2} = 0.1\ \mathrm{rad}.$$

So $\int B d\ell$ kG·m = $p\theta_{defl.}/0.03$ = 330 kG·m, or 15 m @ 22 kG, and
$d = \Delta x/\Delta\theta = 0.7$ mm$/0.025 \times 10^{-3}$ = 30 m, assuming an individual wire spacing accuracy of 0.5 mm.

A sketch of a layout is shown in Fig. 1. The minimum scattering angle is 2 mrad, corresponding to t_{min} = 0.04 at 100 GeV/c. The scattering angle is varied by changing the beam direction. Very small angles can be measured by reducing the beam to a low rate and sending it directly into the spectrometer. If the beam must be left unchanged, steering magnets on the scattered beam can be used instead, requiring an additional small correction to the spectrometer acceptance.

The position-determining wire planes will probably be Charpak type wire proportional counters to obtain better than 100 nsec time resolution, a factor of ten better than spark chambers, to reduce extra accidental tracks. The first planes may have excessive background, requiring the substitution of a counter hodoscope in fast time coincidence with a counter at the end of the spectrometer. Counter scattering at these positions will not decrease the spectrometer resolution. A threshold Cerenkov counter at the end of the system would strongly aid the identification of the reaction.

Bending magnets of aperture 4-in. H × 3-in. V--standard NAL secondary beam magnets--would give a reasonable acceptance: $\Delta\theta_H$ = 1.5 mrad, $\Delta\theta_V$ = 1.0 mrad, or $d\Omega$ = 1.5 μsr. A final wire plane 30 cm H (10 cm V) would give a 3% momentum acceptance, covering a mass range of 3 GeV at 100 GeV/c.

C. Data Collection Rates

The event rate per incident particle is

$$R = n\ell \frac{d\sigma}{d\Omega} \Delta\Omega = n\ell \frac{p^2}{\pi} \Delta\Omega \frac{d\sigma}{dt} .$$

So with a 4-in. liquid hydrogen target at 100 GeV/c,

$$R = 4 \times 10^{23} \times \frac{(100)^2}{\pi} \times 1.5 \times 10^{-6} \frac{d\sigma}{dt}$$

$$= 2 \times 10^{21} \frac{d\sigma}{dt} \text{ events per beam particle.}$$

Assuming the 2.5 mrad secondary beam has an acceptance

$$\Delta\Omega\Delta p = 2 \times 10^{-6} \times 5 \times 10^{-4} = 10^{-7} \text{ sr-GeV/c,}$$

10^{13} interacting protons per pulse will give beam intensities[2] and lowest measurable

$d\sigma/dt$ (at one count per hour for elastic scattering of N^* production) as indicated on the following table.

Secondary Beam per 10^{13} Interacting Protons		$d\sigma/dt$, $\mu b/(GeV/c^2)$, One Count per Hour (10^{16} Interacting Protons)
p	4×10^7	10^{-2}
π^+	8×10^6	6×10^{-2}
π^-	4×10^6	10^{-1}
K^+	4×10^5	1
K^-	2.5×10^4	20
$\bar{p}$	1×10^4	50
p (diffracted)	3×10^9	2×10^{-4}

The above minimum measurable cross sections will probably correspond to t_{max} values in the range 1 - 3 $(GeV/c)^2$ (the diffracted proton beam may go to t = 6).

A reasonable experiment would consist of a 50 hr run per particle or 300 hrs at 100 GeV/c. Lower beam rates than those assumed would decrease the measured t range.

The spectrometer should work equally well at 50 GeV/c. At 150 GeV/c, however, if the magnets are held to about 20 kG, the net mass error will increase from under 50 MeV to about 100 MeV, probably still good enough to separate elastics at the larger cross sections and to do a crude inelastic spectrum. The experiment should be run first at 50 and 100 GeV/c, and if the resolution is satisfactory, 150 GeV/c; time is about 1,000 hrs.

IV. SUMMARY OF MAJOR EQUIPMENT REQUIREMENTS 2.5 MRAD SECONDARY BEAM:

$\Delta p/p = \pm 0.025\%$; $\Delta\theta = \pm 0.12$ mrad

50, 100, 150 GeV/c p, $\pi^{\pm}$, $K^{\pm}$, $\bar{p}$

1,000 hrs

15 m of 22 kG BM, 4 in. × 3 in. aperture, for spectrometer.

Two 5 m, one 1 m, same type BM for beam steering. Two Cerenkov counters for beam (DISC or threshold). One threshold Cerenkov counter 40 cm diam, 50 m long, for spectrometer, probably provided by experimenter. One "standard" small on-line computer.

V. p-p EXPERIMENT WITH THE PRIMARY EXTRACTED PROTON BEAM

Large momentum transfer p-p elastic and inelastic scattering can be studied with the extracted proton beam, using essentially the same spectrometer setup as described above. The mass error from the spectrometer would be the same as before, ±25 MeV at 100 GeV/c; however, the proton beam has a momentum spread of $\Delta p/p = 0.1\%$, $\Delta p = 100$ MeV/c at 100 GeV/c. Nevertheless, as Mobley has pointed out[3] the slow spill resonant extraction process selects a very fine betatron frequency band, and hence narrow momentum interval, for extraction at a given time. So if the approximate time of an event in the beam pulse is determined, the mass error from the beam momentum spread should be sharply reduced. The beam betatron phase space emittance is ~1 mm-mrad, like that of the secondary beam. We wish to measure to a higher momentum transfer in this experiment, however, out to probably $p_\perp = 4$ GeV/c, t about 16 $(\mathrm{GeV/c})^2$. So $\partial M_x/\partial\theta = p_0^2\,\theta/M_x = 100\times4\times10^{-3} = 400$ MeV/mrad. To go to ±25 MeV, the angle spread must be $\Delta\theta = \pm1/16$ mrad, hence the beam must be magnified to 8 mm width. In that case, the net desired resolution of ±50 MeV should be obtained at 100 GeV/c.

The experiment should also be attempted at 200 GeV/c. To keep the spectrometer resolution within reason, the 100 mrad deflection should be retained, increasing the bending field requirements to 660 kG - m. The net mass resolution should be under ±100 MeV, perhaps well under if the beam momentum is well determined and the beam size is magnified further to 1.6 cm. The spectrometer layout--considered to be in a thin target area with movable shielding[4]-- is nearly the same as in Fig. 1. Deflecting magnets to change the scattering angle must be in the scattered beam line, not in the main beam. The initial beam angle with the spectrometer axis should be increased to 30 mrad, rather than the 15 mrad of Sec. III, to get through the extracted beam shield faster. Thirty meters rather than 20 m distance to the first wire plane, and 30 m rather than 15 m of bending magnet will decrease the solid angle acceptance to 3/4 μsr from 1.5 μsr, with $\Delta\theta_H \simeq 1$ mrad, $\Delta\theta_V \simeq 0.7$ mrad. This system should cover the range $1 < p_\perp < 4$ GeV/c or $1 < t < 16\ (\mathrm{GeV/c})^2$ corresponding to scattering angles of 5 - 20 mrad at 200 GeV/c, 10 to 40 at 100 GeV/c.

Note that if it were desired to use a coincidence counter on the recoil proton for elastic scattering, in order to match the above range it would have to subtend quite large angles; e.g. vertically ~25 mrad for a 15 mrad scatter in the high momentum arm at 200 GeV/c. The last wire plane would be at 120 m from the target and 8 m from the proton beam line.

The event rate per proton with a 4-in. H target is $R = 10^{21}\,d\sigma/dt$ at 100 GeV/c and $4\times10^{21}\,d\sigma/dt$ at 200 GeV/c. At one event per hour, for 10^{16} interacting protons/hr, $d\sigma/dt$ can be measured to 10^{-37} cm^2/(GeV/c)^2 at 100 GeV/c and 2×10^{-38} cm^2/(GeV/c)^2 at 200 GeV/c, which should take us nearly to $p_\perp = 4$ GeV/c, $t = 16\,(\mathrm{GeV}/c)^2$ for elastic scattering, if the s dependence disappears and the cross section becomes a function of $p_\perp$ only. [A crude approximation to the present data has the form $d\sigma/dt \sim 10^{-25}\, e^{-p_\perp/0.135}$ cm^2/(GeV/c)^2.] If, however, the cross section continues to have the form suggested by Allaby et al.[5] of $d\sigma/dt = 56\, e^{-s \sin\theta^*/2.77}$ μb/(GeV/c)^2, $d\sigma/dt$ at $p_\perp = 4$ at 200 GeV/c would be $\sim 10^{-52}$ cm^2/(GeV/c)^2, way out of sight.

Reasonable running time should be about 200 hrs for each energy, so 600 hrs are needed for runs at 100, 150, 200 GeV/c, all at maximum available intensity. The runs at 100 and 150 GeV/c would require a front porch and pulsed proton transport magnets, or the machine must be run at the lower energies.

Major equipment requirements: Extracted proton beam, full intensity on a thin target area. $\Delta p/p$ determined (with timing) to $\pm 0.25\%$. Beam magnified to ~ 1.5 cm at target. 30 m of standard BM for spectrometer. One 8 m, one 5 m BM for movable steering magnets. On-line computer.

REFERENCES

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[3] R. M. Mobley, private communication.

[4] W. F. Baker, Research Facilities Design Concepts--Summer 1967, National Accel-Laboratory Internal Report TM-181, May-June, 1969, p. 240.

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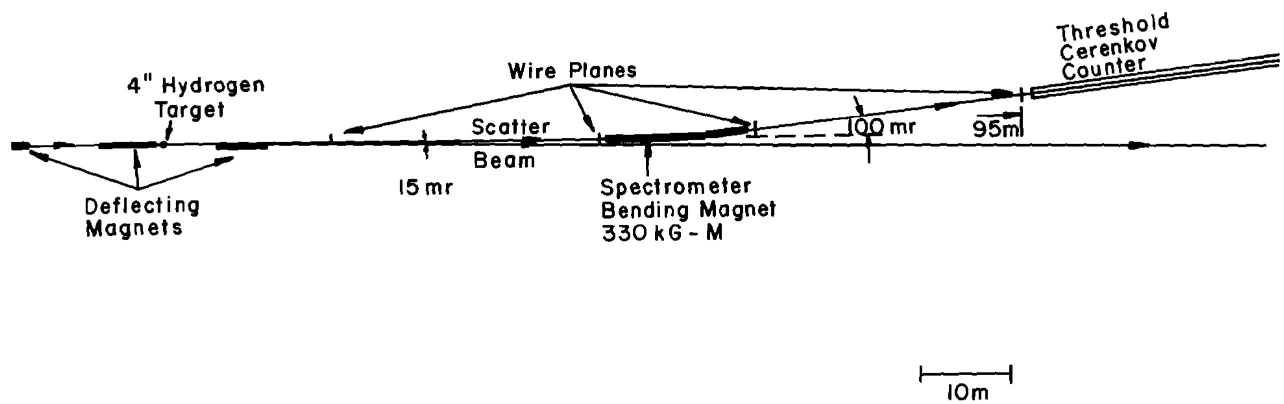

Fig. 1. Schematic layout for 100 GeV/c single-arm spectrometer.