# Λ-P TOTAL CROSS SECTION AND SMALL-ANGLE ELASTIC CROSS-SECTION MEASUREMENTS

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## ABSTRACT

A neutral hyperon beam suitable for measuring the Λ-p total cross section in the energy range 80 to 170 GeV/c is described. It may also be suitable for measuring the elastic cross section in the range $0.05 < t < 1.3\ \mathrm{GeV}^2$ over the same energy range. The former experiment can be performed at beam survey intensities ($10^7$ to $10^8$ protons on target), while the latter requires the full $10^{10}$ intensity of a high-flux secondary proton beam. Equipment requirements are modest for both experiments.

## I. TOTAL CROSS SECTION

The method is to compare the Λ decay rates before and after a hydrogen target. The beam intensity is sufficiently low to permit scintillation counters and possibly even wire chambers to operate in the beam.

The apparatus is shown in Fig. 1. Counters A, B, C, and D define the two decay regions, whose relative lengths are adjusted to give event rates from the two regions optimized for statistical efficiency. Counter pairs Ee, Ff each consist of a small circular counter to detect the proton and a larger ring counter to detect the $\pi^-$ from Λ decay. Such an arrangement can be made about 70% efficient for Λ's and give a high rejection of other decays. An anticoincidence "sleeve" T surrounds the target to eliminate interactions in the target. Thus the signals for the two desired processes are:

| | |
|---|---|
| Decay before target | $\overline{A}BEe$ |
| Decay after target | $\overline{ABCT}DFf$. |

The decay angles are measured by wire planes. About 6 m from the target is a spectrometer magnet. Because of the low Q value of Λ decay, an 8 in. gap and 20 in. width give 100% solid-angle and momentum-band coverage. If the magnet is 2 m long at 15 kG, the momentum and angle errors are well matched and give a mass resolution of about 10 MeV at the Λ mass.

The target and decay regions can be enclosed in the same vacuum pipe to reduce backgrounds.

For the arrangement shown, the target is 1 m long, giving about 20% interaction of the $\Lambda$'s. The decay length is adjusted so that the event rate is about the same in the second region as the first; thus the total length is effectively 2 m or 0.25 decay lengths at the average beam momentum. Allowing a factor 0.8 for loss due to decay protons that interact in the target, 0.7 for trigger efficiency, and another 0.7 for "whatever"

$$\frac{\Lambda \text{ decays}}{\Lambda \text{ flux}} = 0.25 \times 0.8 \times 0.7 \times 0.7 = 0.1 .$$

We choose an event rate of 10 per pulse, or $10^6$ events in a $10^5$ pulse (10-day) run. Since the statistical error in the cross section is about $6/\sqrt{N}$ for N events, a 2% measurement in each of 10 energy bins is thus possible. Systematics probably limit the precision to this level. Thus a flux of 100 $\Lambda$/pulse will suffice.

The calculations by Walker in the 1968 Summer Study report indicate that there are about 80 neutrons per $\Lambda$ at this distance from the target. Thus the total beam flux is on the order of $10^4$. Assuming the scintillation counters are 0.005 interaction lengths (1/8 in.) and the wire chambers somewhat thinner, each should be able to handle the rate, even if the estimates of the $\Lambda/n$ ratio are off by an order of magnitude.

Using the curves in the report on the neutral beam, and assuming a solid angle of $3 \times 10^{-7}$ radians ($\Delta\theta$ = 0.3 mrad)[1] since there are 120 $\Lambda$ per proton per steradian at this distance from the target, the required beam intensity is obtained from

$$120 \times 3 \times 10^{-7} \times N = 100$$

$$N = 3 \times 10^6 .$$

Assuming 30% targeting efficiency, the experiment can run at $10^7$ protons on target. Even if the estimates of $\Lambda$ flux are off by an order of magnitude the experiment remains "parasitic."

Because of the high mass resolution, true background should be negligible. False triggers due to beam and regenerated $K_S^o$ decays should be an order of magnitude lower than true events. Even fewer triggers will be generated by neutron interactions in the counters. All other sources of background seem negligible. Thus it is unlikely that the false trigger rate will exceed the true one, and the experiment can run at 10 events/pulse without unduly burdening the data retrieval system.

Since the geometries of the trigger systems for the two decay regions are identical, the absolute trigger efficiencies need not be known. Elastic $\Lambda$ scatters with a momentum transfer $< 0.02\ \mathrm{GeV}^2$ will escape detection, but these constitute a small part of the total cross section (about 2 mb at most). The major source of systematic error is the correction for decay products that interact in the target and counters. The target can be a thin-walled metal tube with mylar end windows.

## II. ELASTIC SCATTERING

If the formula $d\sigma/dt = 100e^{-10t}\ \mathrm{mb/GeV}^2$ is a reasonable guess for the elastic cross section, it seems possible to cover the first five decades of the cross section in this beam, i.e., the region $0.06 < t < 1.2\ (\mathrm{GeV})^2$. The technique is to observe an off-beam $\Lambda$ decay in coincidence with a proton at right angles to the beam. The lower limit is set by the necessity of detecting the proton, the upper by counting rate.

The range of angles covered is about 2 to 12 milliradians, as compared to the maximum $\Lambda$ decay opening angle of about 10 mrad. Thus the same spectrometer described for the total cross section can be used, slightly shortened, with high solid-angle efficiency. There is some loss in solid angle due to the necessity of keeping the wire planes clear of the beams, which must be high intensity ($\sim 10^8$ neutrons/pulse).

The proton trigger is illustrated in Fig. 2. A "Venetian blind" is formed of 0.3 mm × 1 cm scintillators edge-on to the beam. Alternate scintillators are connected to two different phototubes. The trigger requirement is that only one of the two phototubes see a signal. The Venetian blind is followed by a short range telescope to measure proton momentum up to 400 MeV/c ($t = 0.15$). Pulse height in the last two counters that fire is recorded, which should provide a 5% measurement of t. All of this is inside the target vacuum. For higher momentum protons, a magnetic spectrometer is provided. The field is horizontal for ease in providing a large solid angle. It needs to have a gap as long as the target, here assumed 8 in. If the gap width is 30 in. and the magnet length also 30 in., it covers about a quadrant.

Since the $\Lambda$'s are now off-beam, a $\Lambda$ trigger that excludes $K_S^o$ decay is no longer possible. Thus there will be a trigger rate from $K_L^o + p \rightarrow K_S^o + P$ that may exceed that for true events. Accidental triggers from on-beam decays are suppressed by a small ring counter centered on the beam.

Assuming a useful $\Lambda$-decay path of 3 m (decay probability 0.3), 70% solid angle coverage on the $\Lambda$ and 25% on the proton, the detection efficiency is 0.05. Given the cross section above, the mean free path for an interaction with $t > 0.06\ \mathrm{GeV}^2$ is 50 m, and the interaction rate in the target is $4 \times 10^{-3}$. Thus the total counting rate is $2 \times 10^{-4}$ per $\Lambda$.

The experiment is run in two parts. Each collects $10^6$ events over three decades of the cross section, with an overlap in the middle decade. For the higher three decades, the required beam intensity, assuming 30% targeting efficiency, is

$5 \times 10^8$, using the same solid angle as in the total cross-section measurement. For the lower three decades, the range telescope is not used, and the field in the proton spectrometer is doubled. Since the scattering angle is larger, a larger beam solid angle can be tolerated, assuming a counting rate equal to that in the upper three decades, with the beam raised to its limit of $10^{10}$. To add two more decades would require a larger $\Lambda$ spectrometer, and a slower counting rate even after again opening the solid angle. Even in the second three-decade part, the event rate from neutron interactions will be pushing some of the scintillators near their counting rate limit.

The target is a mylar "condom" 8 in. × 3/4 in.

The experiment as shown would measure the logarithmic slope of $d\sigma/dt$ to about 1% in each of several energy bins. It is hard to imagine any way to do this well in tertiary "tagged" beams.

Clearly, this design is in a more primitive state than that for the total cross section. Detailed Monte-Carlo studies are necessary to optimize the trigger design to keep trigger rates reasonable.

## Equipment Requirements

Both experiments need a PDP-8 type data harvester.

### Total Cross Section

1. Spectrometer magnet 8 in. × 20 in. × 80 in. (gap, width, length).
2. 10 wire planes (magnetostrictive).
3. 9 to 12 scintillation counters and accompanying logic.
4. Hydrogen target 1 in. diameter × 40 in. long, thin metal walls and mylar end windows, mounted in 4 in. × 140 in. vacuum pipe with 5 of the scintillators.

### Elastic Scattering

1. Magnet and wire planes from total cross section.
2. Additional proton spectrometer magnet 8 in. × 30 in. × 30 in.
3. 6 more wire planes for proton spectrometer.
4. About 20 scintillation counters.

## REFERENCE

[1] T. G. Walker, Secondary-Particle Yields at 200 GeV, National Accelerator Laboratory 1968 Summer Study Report B.5-68-24, Vol. II, p. 59.

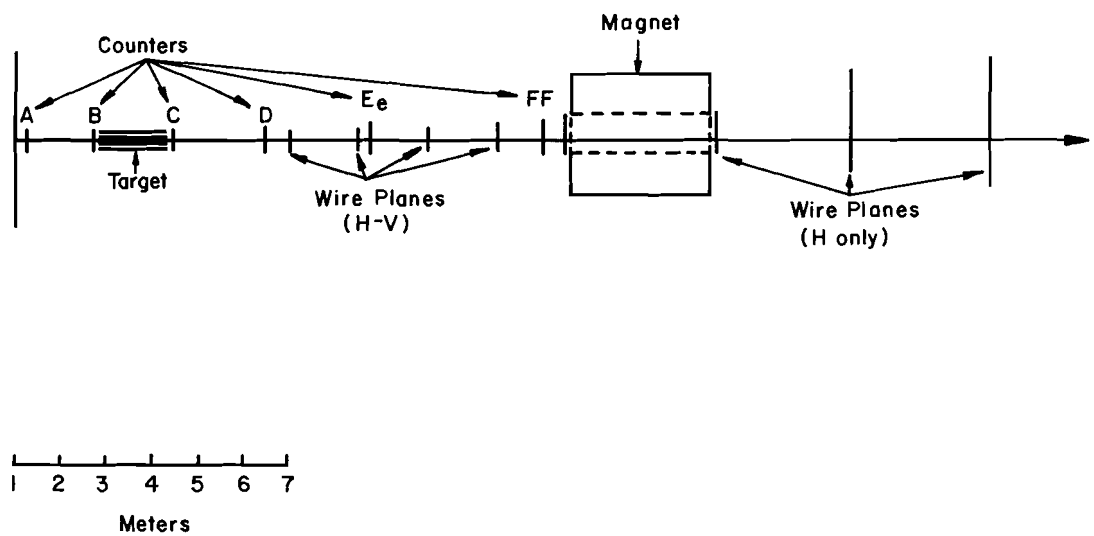


Fig. 1. Lambda-decay detector and target arrangement for total cross-section measurement.

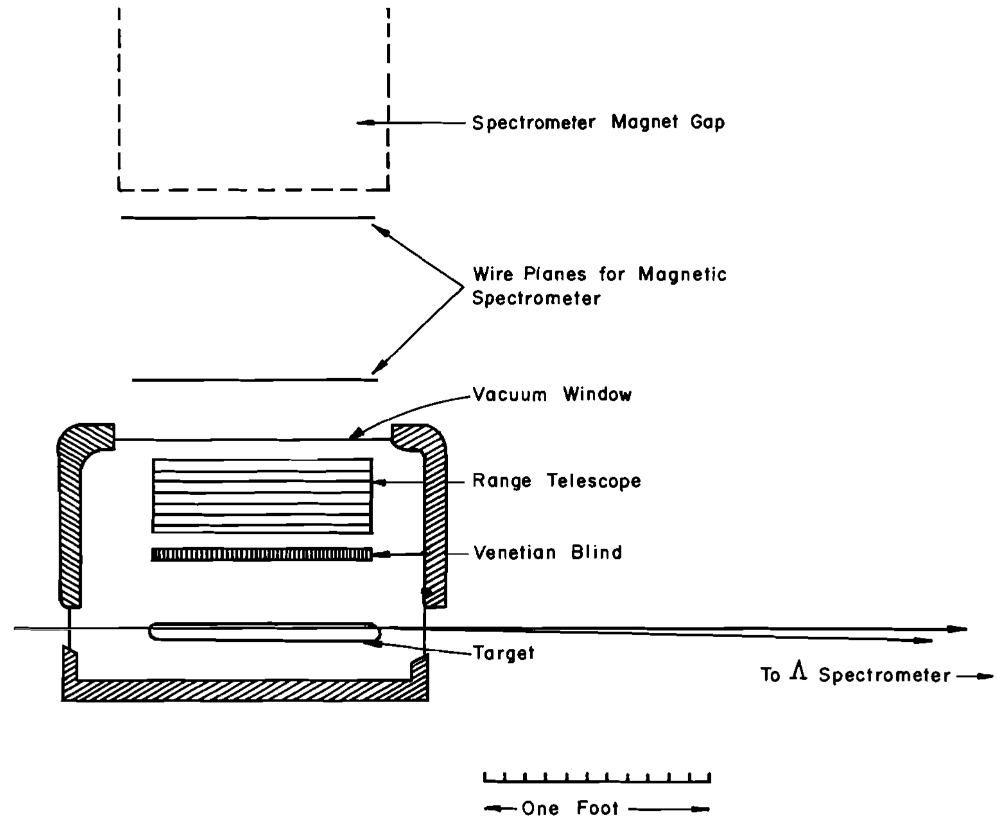


Fig. 2. Recoil proton detector.