NAL PROPOSAL No. 235

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Neutron Small-Angle Elastic Scattering

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A Supplement to Experiment 4

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Introduction

Experiment 4 is currently set up and operating satisfactorily in beam M3 in the Meson Area; with suitable beam conditions and an operating hydrogen target, significant data acquisition should commence very soon.

This supplemental proposal stems from the observation that these same apparatus, targets, and beam can be used with very minor modification to study very small angle neutron elastic scattering in a range of four momentum transfer totally inaccessible with charged hadrons due to coulomb scattering.

Physics

It was observed several years ago[1] that pp elastic scattering showed evidence of a break in the slope of the diffraction peak near $-t \simeq .1\,(\mathrm{GeV}/c)^2$. Subsequent ISR measurements confirmed this break and emphasized the necessity for careful measurements down to the smallest accessible values of $|t|$.[2] Neutron experiments by our group confirmed that this phenomenon is restricted neither to protons nor to high energies.[3] However coulomb scattering in the pp system is equal to nuclear

(strong interaction) scattering at $|t| \cong .002(\mathrm{GeV}/c)^2$, and in view of the rapid $|t|^{-2}$ dependence of the coulomb scattering, critical information cannot be gathered on the pp interaction for $|t| \leqslant .005(\mathrm{GeV}/c)^2$.

There are several motivations for studying the hadronic elastic scattering at very small t. First, there is the obvious question of whether the exponential slope seen over the range $.005 < |t| < .1(\mathrm{GeV}/c)^2$ extends to still smaller $|t|$, or whether there might be yet another change in slope. In view of the possibly rising pp total cross sections, it is of interest to search for evidence of a more diffuse outer "cloud" of the nucleon interaction, which may become more opaque at higher energy. Second, the elastic scattering on heavier nuclei would allow a systematic determination of nuclear radius as functions of atomic number and energy. Combined with the systematic search for the A and E dependence of total cross section in Experiment 4A, these data will provide a more complete picture of the strong interaction in nuclear matter at these high energies. This kind of information is totally inaccessible to the ISR. Third, it should be possible to observe the interaction of the neutron magnetic moment with the nuclear coulomb field. Although this effect should be accurately predictable, it has not been observed to date.

Beam and Detector

The neutron beam at 1 mr. production from a tungsten target in the proton beam has a spectrum given in Figure 1 and an intensity of about 250 neutrons/(sterad proton), based on

the SEM monitor of proton flux incident on the target . It has not been possible to date to make a definitive measurement of the calorimeter energy resolution; however brief runs with no bending magnets energized in the M3 beam which provide a mixed beam of elastic protons together with pions, inelastic protons, and neutrons gives the spectrum of Figure 2, suggesting that our detector resolution is no worse than 20% F.W.H.M., and may indeed be better. Since the elastic scattering cross section near 0° is proportional to p^2, the neutron spectrum effective in elastic scattering is enhanced by this factor in the data collected in this experiment.

The Experiment

A hodoscope of ten small counters, each 3/4" x 2" (approximately 2 x 5 cm^2) has been built. These would mount behind an iron converter plate and ahead of the calorimeter. The counters are adjustable vertically, so that they may constitute a continuous hodoscope of 7.5 inches or a spaced hodoscope of 15 inches. The detector is located about 650 feet (200 m) from the hydrogen and solid target station, so that each counter subtends an angle of $10^{-4} \times 2.5 \times 10^{-4}$ steradians, and the array covers a range of 10^{-3} to 2×10^{-3} radians (depending on whether close-packed or spaced). At 100 and 200 GeV, the apparatus thus covers a range of 0.0001 to 0.04 and 0.0004 to 0.16$(GeV/c)^2$ in $|t|$ respectively. One might think that an array of annular rings would be the ideal configuration for this experiment, however the one-dimensional hodoscope is very suitable. If the scattering is represented

by a pure exponential in $|t| = p^2\theta^2$, then $d\sigma/d\Omega = K \exp(-Bp^2\theta^2) = K \exp(-Cr^2)$; or $d\sigma/d\Omega = K \exp(-Cx^2)\exp(-Cy^2)$. If the width of each counter element is constant in x, then the x dependence factors out and the counts in each y counter element determine the slope C. To the extent that the scattering deviates from a pure exponential the exact detector geometry may be unfolded to extract $d\sigma/d\Omega$ and $d\sigma/dt$. In practice the narrow width in x of each counter will facilitate any unfolding. The calorimeter energy resolution will also be carefully determined from proton calibrations and will also be unfolded. Beam halo will be subtracted by taking data with targets in and out of the beam.

In practice, each detected event will be recorded on tape with the calorimeter pulse height, the y-address of the appropriate hodoscope element, and the target status. Suitable anticoincidence counters of course constrain the geometry and help assure the event elasticity. Systematic non-uniformities in the separate counters and in the calorimeter response can be eliminated by translating the entire detector assembly in the y-direction (relative to the beam axis).

Data Rate

The limiting data rate will be for hydrogen, and as that case is also the most interesting we will consider it as an illustration. In general (for totally imaginary elastic scattering)

$$\frac{d\sigma}{d\Omega} = \left(\frac{p\sigma_T}{4\pi\hbar}\right)^2 e^{-Bp^2\theta^2};$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{0^\circ} = \left(\frac{p\sigma_T}{4\pi\hbar}\right)^2 .$$

For σ_T = 40 mb, $(d\sigma/d\Omega)_{0^\circ} \cong 2.5 \times 10^{-22}$ cm^2/sterad and $\cong 10^{-21}$ cm^2/sterad for p of 100 and 200 GeV/c. Each hodoscope element subtends a solid angle of 2.5×10^{-8} sterad, and the 4-foot liquid hydrogen target contains about 9 g cm^{-2} of hydrogen, so that each hodoscope element (not in the direct beam) will receive a count for each 3×10^4 (100 GeV) to 7×10^3 (200 GeV) beam neutrons. It is convenient to operate our neutron beam at a flux of about 10^4 neutrons per pulse into a spot less than one cm diameter at the detector. By operating at this flux we could collect one event per channel or about 10 events total per pulse. At 10^4 pulses per day, one week of data collection would suffice for excellent hydrogen data including target out subtraction.

We believe that we should be able to collect adequate data on hydrogen plus heavy elements in one month of good operating conditions.

Status of Experiment

The counters, electronics, and programs are now operating in Experiment 4A. The only change required will be the replacement of the front counter assembly now on the neutron detector with the hodoscope array, which is already assembled and tested. The targets, counting area, computer, and all other components would remain as in Experiment 4A.

References

1. R.A. Carrigan, *et al.*, Phys. Rev. Lett. *24*, 683 (1970).
2. G. Barbiellini, *et al.*, Phys. Lett. *39B*, 663 (1972).
3. F.E. Ringia, *et al.*, Phys. Rev. Lett. *28*, 185 (1972).

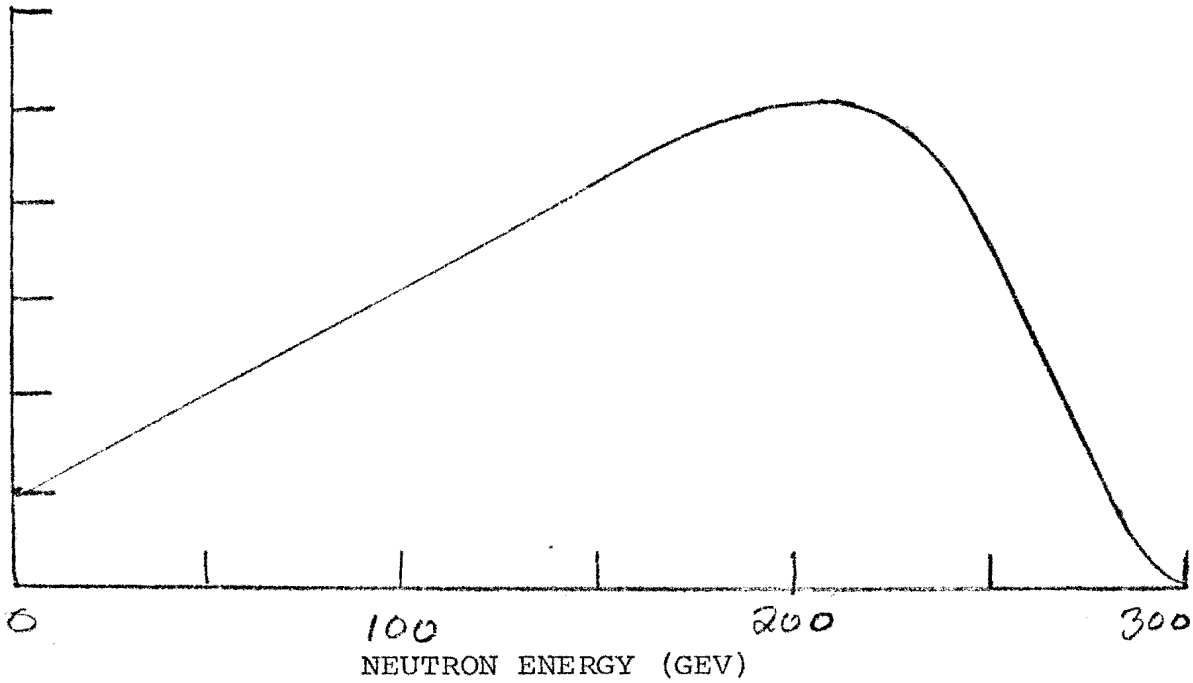

Figure 1. Neutron energy spectrum from 300 GeV protons incident on a tungsten target. The neutron production angle is 1.0 mr. (The neutron detector resolution function is not unfolded.) The energy scale is deduced from calibration with 300 GeV protons (Figure 2).

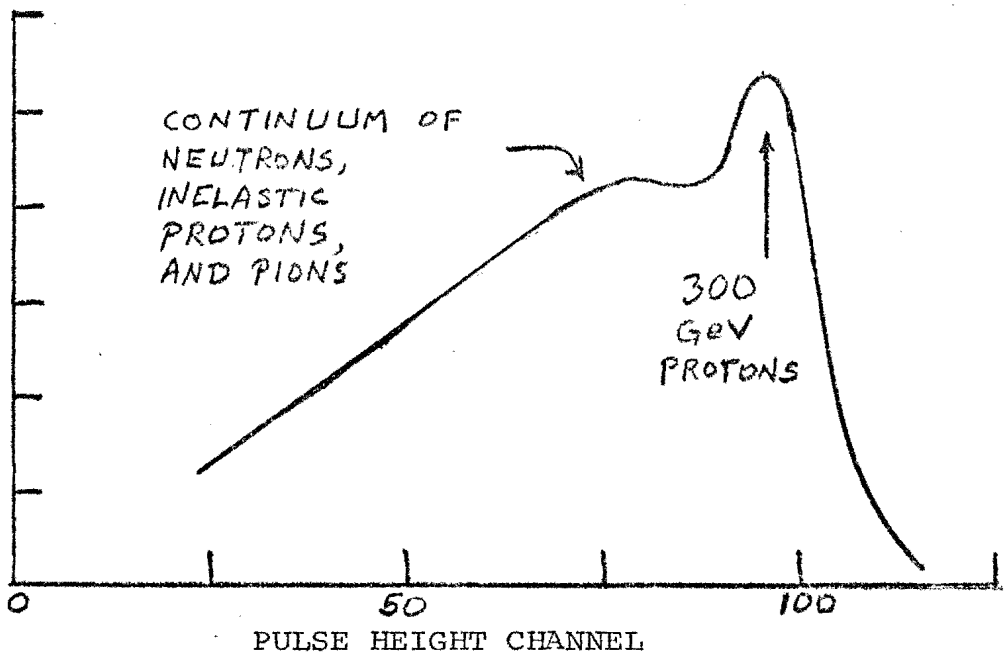

Figure 2. Pulse height spectrum from the calorimeter in the M2 beam channel with no magnets energized. The beam presumably contains diffraction-elastic protons together with a continuous spectrum of inelastic hadrons similar to the neutron spectrum of Figure 1.