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A NEUTRON BEAM FOR NAL

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ABSTRACT

Longo has pointed out the desirability of a neutron beam at NAL. Below we detail a possible neutron beam, its desired characteristics, and some experiments for it.

We propose that the neutron beam be brought out at 0° through a 10^{-8} sr collimator (1 cm aperture at 100 m from the target), preferably from target station #2. There are two strong motivations for 0°: 1) the absolute flux at full energy is an order of magnitude greater than at even 3 mrad, and 2) the spectrum is peaked at the full proton energy (200 GeV). The need for high intensity is self-evident; the desire for maximum energy is not only that the highest energies have the greatest interest, but also the fact that the neutron detection devices (e.g. ionization calorimeters) have a finite energy resolution (±5-20%) and therefore the overall system resolution (beam plus detector) is best using the relatively sharp end-point cutoff spectrum of the 0° neutron beam. It is also true that the ratio of neutrons to K^0 is best at 0°, and that an energy-sensitive detector tuned to 200 GeV is less sensitive to lower energy contaminants than one tuned to a lower energy (e.g. the peak of the 3 mrad spectrum at 140 GeV).

The requirement on the neutron beam angular divergence is set by the need in some neutron experiments to be sensitive to $|t| \approx 10^{-4}$ $(\mathrm{GeV})^2$. Since $(p\theta)^2 \approx |t|$, this limit corresponds to $\theta \sim 5\times10^{-5}$ radians for p = 200 GeV. The flux of neutrons through an 10^{-8} aperture at 0° is about 10^{-4} per interacting proton on a Be target integrated over the top 40 GeV of the neutron spectrum. This assumes that the neutron spectrum is just that given by the inelastic proton spectrum and uses the Hagedorn-Ranft calculations as given by Awschalom and White for protons on beryllium.[1] Experience at the Bevatron and the AGS agree in the qualitative equality of the n and p inelastic spectrum. For 10^{13} protons on a Be target of 1.3 interaction length, the useful (top 40 GeV) neutron flux would be about 3×10^{8} per pulse. The total flux would be about twice this. The 0° and 3 mrad neutron spectra are reproduced in Fig. 1 on a linear scale.

The neutron beam must be cleared of γ's by interposing 10-30 radiation lengths of Pb or U early in the beam (between the target and the defining collimators). This would correspond to 0.3-1 nuclear mean free paths and would attenuate the neutron beam by a factor of 1.5-3. This γ (and shower) absorber would also significantly reduce any charged particle contamination in the beam through multiple coulomb scattering, even without a sweeping magnet. For example, $\langle\theta\rangle_{rms} \approx 5\times10^{-4}$ radians for a 200 GeV/c charged particle traversing 25 r.l. and correspondingly more for lower momenta. Magnetic sweeping would obviously also be used to clean the beam. Here we propose the use of alnico permanent magnets buried in the shield, to obviate any problems of radiation damage, servicing, etc. (Such a magnet is in use with our Bevatron neutron beam.) A one tesla-meter magnet will deflect a 200-GeV particle 1.5 mrad, or well out of the beam channel. A simple alnico magnet can readily achieve a gap field of 0.1 tesla, and trivial improvement would give 0.2-0.3 T. Cross sections of such magnets are noted in Fig. 2.

The possible layout of such a neutron beam is sketched in Fig. 3. At this time the possible compatibility of this beam with various γ, K^o, or 0° reduced-intensity proton beams is recognized, but no serious attempt at a design incorporating more than this single objective has been attempted as yet.

From the bias of our past experience with neutron beams (at LRL and BNL) it seems more important that the beam be at 0° than that the full proton flux be used in producing it. For example, if a thin target station or even the septum of a beam-splitting magnet was struck by 1% of the beam, the 10^6 0° neutrons resulting would be useful for two of the three experiments discussed below. For experiments requiring differing neutron fluxes the intensity could be varied simply by varying the diameter of collimators in the last few meters of the shield, or after the shield.

NEUTRON BEAM EXPERIMENTS

A. Neutron Total Cross Sections

Motivation: The np σ_{total} is as important as the pp σ_{total} in determining the asymptotic validity of various notions concerning both the NN cross section and concerning $\sigma(np)-\sigma(pp)$. It is also important to determine $\sigma(np)+\sigma(pp)-\sigma(pd)$, the Glauber screening correction. There is evidence below 30 GeV that both $\sigma(np)$ and the Glauber correction differ from what had been guessed prior to measurements, displaying an energy variation previously unexpected. As an easy extension, the measurement of σ_{total} of neutrons on elements He through U can study any possible energy dependence of the A dependence of nucleon-nuclear cross sections. This relates directly to the optical parameters of the nucleon-nucleon interaction, which will vary with energy if σ_T and/or $d\sigma/dt$ (elastic) vary.

Method: A "good-geometry" attenuation cross section is made, using (in this order along the neutron beam) a neutron beam monitor (thin CH_2 target and monitor telescope), target, anticoincidence counter, drift space (about 200 meters) an iron converter of about 10 g/cm^2, a series of "cookie" counters subtending different solid angles about the beam axis from $\pm 5 \times 10^{-5}$ to $\pm 5 \times 10^{-4}$ radians, and finally an ionization calorimeter (iron-scintillator sandwich system). All of this is identical to experiments already completed at 6, 19, and 27 GeV/c at LRL, BNL (by groups including the author) and CERN (by the Karlsruhe group). In particular, the ionization calorimeter need be no larger or "deeper" than those already in use. Measurements of σ_T precise to 1.5% are now being reported at these lower energies.

B. Neutron-Proton Forward Elastic Scattering

Motivation: Any shrinkage of the np elastic forward peak would be interesting, as would a detailed comparison of the np and pp scattering at the same energy. At larger $|t|$ evidence of breaks or dips in the differential cross section would be of obvious interest.

Method: Again measurements at LRL, CERN, and BNL have been reported, and the method is well established. A wire-plane and magnet spectrometer system to detect the target proton recoil is used with a neutron-sensitive iron-plate spark chamber. The neutron chamber could be instrumented to serve as both a vertex determining device (by sparks) and energy measuring device (by scintillation counters). Both functions could be combined by using planes of proportional counters or by viewing a large NaI crystal by image tubes as well as by P.M. tubes. Even with the neutron energy uncertain, the beam collimation, the proton momentum and angles, and the neutron angles specify the neutron energy and scattering momentum transfer. The use of anticounters in neutron experiments to eliminate inelastic final states is obviously practical and desirable. The range of t accessible should correspond to the range accessible in πp scattering experiments.

C. Neutron-Proton Backward Scattering

Motivation: The backward np scattering, or nucleon charge-exchange scattering should be a fundamental one-pion exchange process; however, current theories have not yet explained the existing meager data. The experiments are currently being extended to 28 GeV by the groups already mentioned. The charge-exchange peak is characterized by a width much narrower than the forward peak, and a magnitude falling as p^{-2}. The cross section at 180° is about 5% of the 0° cross section at about 5 GeV, and should be down by about 3×10^{-5} relative to the 0° cross section at 200 GeV.

Method: Again, following plans for a corresponding AGS experiment, a downstream wire-plane magnet proton spectrometer detects the forward full energy proton, and neutron time-of-flight counters detect the slow neutron angle and energy. It is this experiment more than the previous two that would need the full 10^8 neutron beam. The resolution required of the proton spectrometer is modest ($\Delta p/p \sim 1\%$) and the aperture is small (0.1 radian) although it must extend to 200 GeV.

D. Neutron Diffraction Dissociation

Motivation: Present theoretical ideas and experimental data suggest that Pomeron exchange processes may remain nearly energy-independent at higher energies. Since more such channels open up at a given t as energy increases, they may come to dominate the inelastic processes at very high energy. Further, since $|t|$ is very small and no quantum numbers are exchanged, these processes may proceed with a cross section proportional to A^2 instead of the $A^{2/3}$ usually associated with reactions on heavier nuclei.

A particularly clean diffraction dissociation process to study is $n + A \to N^* + A$ where $N^* \to p + \pi^-$. Since the incident neutral baryon goes to two charged particles, it would be essentially unnecessary to label the particles, as the positive particle must almost certainly be the proton.

Method: A target (of H or a heavier element) in the neutron beam would be followed by a rather conventional wire-plane and magnet spectrometer ($\Delta p/p \sim 1\%$) triggered by the emergence of two charged particles. The required aperture should be modest, the cross section for the known isobars should be at least a fraction of a millibarn, so that the event rate would permit a rather modest beam flux.

Other experiments with neutrons such as forward and backward inelastic scattering obviously suggest themselves. Our main conclusions are that the neutron beam plus existing detectors such as the ionization calorimeter make quantitative neutron physics accessible at 200 GeV, and that the physics interest in such experiments warrants inclusion of such a beam at NAL.

REFERENCE

[1] M. Awschalom and T. White, Secondary Particle Production at 200 GeV, National Accelerator Laboratory FN-191, June 9, 1969.

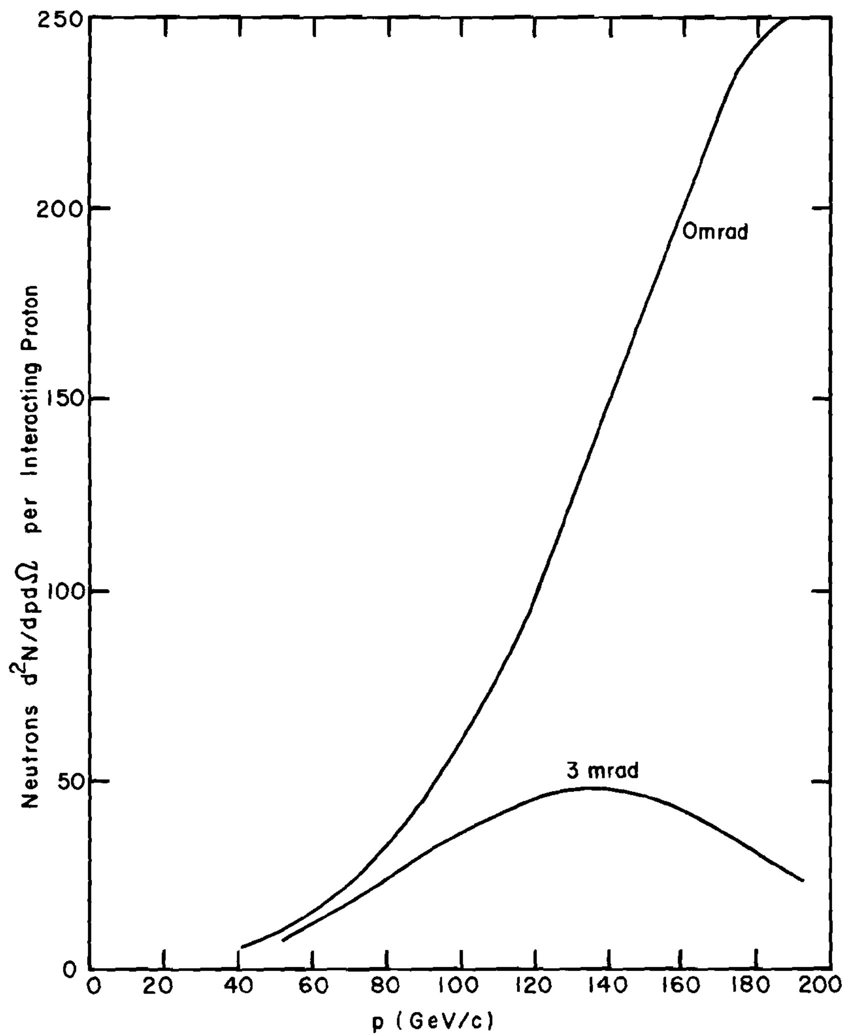
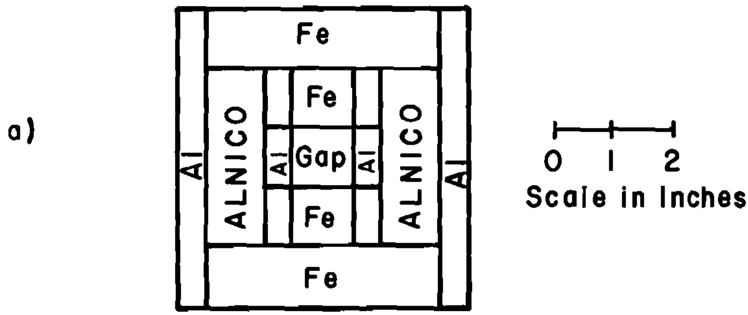


Fig. 1. The neutron spectrum (taken from the inelastic proton spectrum of Awschalom and White) at 0 and 3 mrad production, for 200-GeV protons on a Be target.



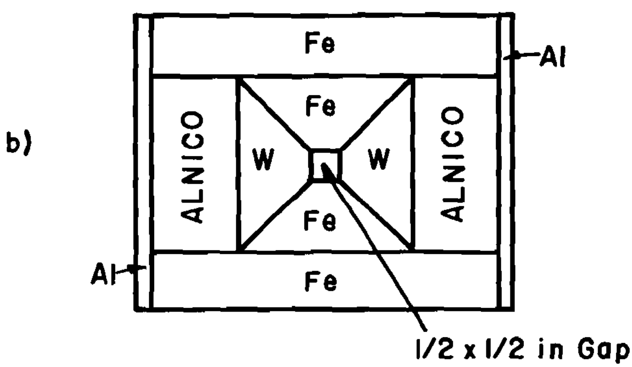


Fig. 2. Cross sections of Alnico permanent magnets useful in sweeping charged particles from a neutron beam. a) Existing 1 kG magnet. b) Proposed 2 kG magnet.

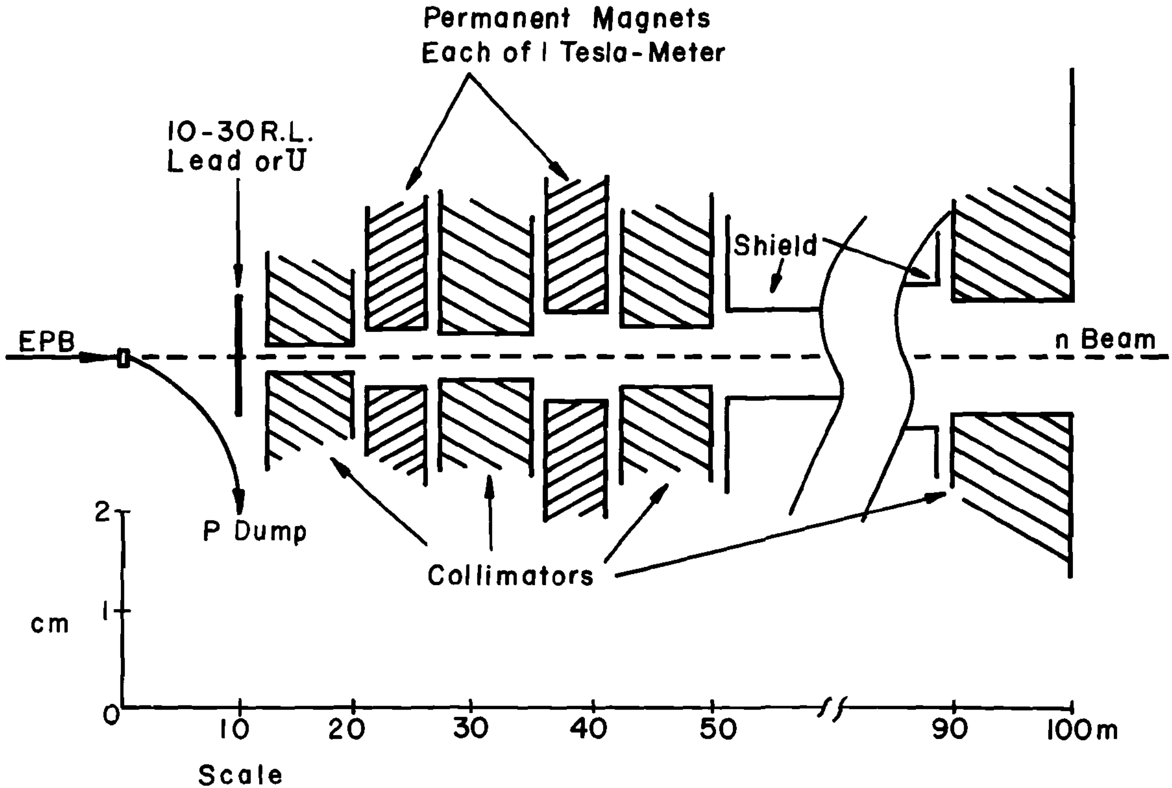


Fig. 3. Schematic representation of a possible neutron beam subtending $\pm 5 \times 10^{-5}$ radian from a target in the EPB. Horizontal and vertical scales differ by 10^3.