NAL PROPOSAL No. 93

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SMALL-ANGLE CHARGE EXCHANGE REACTIONS
$\pi^- + p \rightarrow \pi^\circ + n$ and $\pi^- + p \rightarrow \eta + n$
FROM 50 to 200 GeV/c

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NAL EXPERIMENTAL PROPOSAL

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ABSTRACT

We propose to measure the differential cross sections in the forward direction for the reactions $\pi^- + p \to \pi^0 + n$ and $\pi^- + p \to \eta + n$. Measurements will be made at four momenta spanning the newly-accessible energy region, typically at 50, 100, 150, and 200 GeV/c. These measurements will include four-momentum transfers from t = 0 out to approximately t = -1 $(\text{GeV/c})^2$. We will also make a study of neutral final states which decay into more than two γ's. The interaction will occur in a liquid hydrogen target, and the decay γ's will be detected using an array of multiwire proportional chambers separated by Pb sheets.

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This proposal is a follow-up to our June 26, 1970 Letter of Intent, which is included here as an Appendix.

Physics Justification

The charge-exchange reaction allows the most direct experimental check on the validity of Regge theory at these high energies, because it can be described in terms of the exchange of a single Regge pole. The forward $\pi^o n$ reaction proceeds via ρ exchange, the ηn via A_2 exchange.

The charge-exchange differential cross-sections up to 18 GeV/c have been described very well by simple Regge exchange.[1] These measurements produced a basis for confidence in the merits of the Regge model, at a time when it was in disrepute because of the difficulties in describing elastic scattering cross sections. Subsequently, the charge-exchange polarization measurements[2] showed that it is inadequate to use only a single Regge pole to describe this reaction at 11 GeV/c. The next sensitive test of the simple Regge-pole exchange model will very likely be the measurements of the charge-exchange differential cross sections in the 100 GeV/c momentum region.

In addition, the rate of decrease with energy of the zero-degree charge-exchange cross section is a sensitive measure (via the optical theorem) of the rate of mutual approach of the $\pi^- p$ and $\pi^+ p$ total cross sections, and is thus a measure of how close we are to "asymptopia."

$$\left[\mathrm{Im}\, A_{ex}(t = 0)\right]^2 = \frac{(\Delta\sigma)^2}{32\pi\hbar^2} ,$$

where A_{ex} is the charge-exchange amplitude, and $\Delta\sigma$ is the difference between the $\pi^- p$ and $\pi^+ p$ total cross sections. Using the observation[3] that the real and imaginary parts of the charge-exchange amplitude are approximately equal at 10 to 20 GeV/c, and converting to convenient units, we obtain

$$\left[\frac{d\sigma_{ex}}{dt}(t = 0)\right] = 50\ (\Delta\sigma)^2,$$

with $d\sigma_{ex}/dt$ in $\mu b/(GeV/c)^2$ and $\Delta\sigma$ in mb.

Let $\delta_{\pi p}$ be the percentage error in a measurement of the total πp cross section σ, and let δ_{ex} be the percentage error in $d\sigma_{ex}/dt$. In order that the measurement of $\sigma(\pi^- p)$ and $\sigma(\pi^+ p)$ produce the same error in $\Delta\sigma$ as does a measurement of $d\sigma_{ex}/dt$, we must have

$$\frac{\delta_{ex}}{\delta_{\pi p}} = 2\sqrt{2}\,\frac{\sigma}{\Delta\sigma} \quad .$$

The high energy total $\pi^{\pm}p$ cross section parametrization of Lindenbaum[4] predicts that $\sigma = 23$ mb and $\Delta\sigma = 0.7$ mb at 100 GeV/c. This means that, at 100 GeV/c, a 10% measurement of $\frac{d\sigma_{ex}}{dt}$ $(t = 0)$ is equivalent to a 0.1% measurement of both the $\pi^- p$ and $\pi^+ p$ total cross sections.

We also intend to study the production of I = 0 and I = 2 neutral final state bosons which decay into more than two γ's. This study will include mass distributions of $\pi^o\pi^o$ and $\pi^o\gamma$ final states as well as production and decay angular distributions for the various mass regions. Among the interesting physics to come out of these data will be a search for high mass neutral resonances, and the high energy angular distributions of known resonances, such as the f^o meson.

Experimental Arrangement

The proposed experimental setup is shown in Fig. 1. The beam required is a moderate intensity (~ 10^6 π^-/pulse), moderate resolution ($\Delta p/p \simeq 1\%$) pion beam, capable of a momentum range from 50 to 200 GeV/c. A Cerenkov counter is required in this beam to separate the π^-'s from the K^-'s and $\bar{p}$'s.

The incident beam angle must be known to ± 0.07 mrad at the highest momentum of 200 GeV/c. To achieve this beam divergence accuracy we will use two beam hodoscoopes separated by 60 ft. Each hodoscope will have 2-mm-wide counter elements.

The charge-exchange reaction will occur in a 3-ft.-long liquid hydrogen target. This target will be surrounded by anticoincidence counters. The downstream anti counter will veto only charged particles; the side anti counters will consist of Pb-scintillator sandwiches, and will veto γ's as well as charged particles.

The downstream γ's will be converted in an array of multiwire proportional chambers (MWPC), separated by Pb plates. The distance D between the hydrogen target and the MWPC array will be varied as a function of incident beam momentum:

$$D = p$$

with p the momentum in GeV/c, and D the distance in feet.

A large bending magnet just downstream of the hydrogen target will be used to deflect the remaining beam particles, and most of the scattered secondary charged partaicles, out of the way of the MWPC array. If this magnet were not used, the limitation in our data rate would be the loading up of the MWPC array with charged tracks resulting from the hydrogen interactions of ≈ 10% of the beam particles.

This magnet has a field of 20 kG, a length of 12 ft., and a clearance aperture of 16 by 16 inches.

The MWPC array will consist of 11 chambers, each 40-inches square, with both X and Y readout. The first three chambers will not be separated by Pb plates, but will be used for further rejection of charged particles. The total thickness of the Pb sheets separating the remaining chambers will be about five radiation lengths, providing a conversion efficiency of 97% per γ-ray, with a minimum traversal of three chambers per shower. The spatial resolution of these chambers will be $\pm$ 1 mm.

The γ-γ opening angle resolution will vary from $\pm$ 2% at 200 GeV/c to $\pm$ 4% at 50 GeV/c; the resolution is poorer at 50 GeV/c because the fixed-length hydrogen target represents a larger fraction of the hydrogen-target-to-MWPC distance. This resolution should provide excellent separation of π^o's and η's. To insure a clean sample, and also to provide good resolution in t (the four-momentum squared) we will accept only events with opening angles between 1.0 and 1.16 times minimum. The minimum allowed γ-γ opening angle is given by

$$\theta_{\gamma\gamma} \min \cong \frac{2m_{\pi^o}}{p} .$$

This opening-angle cut will include 50% of the events.

The resolution in t resulting from this experimental arrangement, plus the opening angle cut, will be $\pm$ .005 $(GeV/c)^2$ at t = -.005 $(GeV/c)^2$ and $\pm$ .07 $(GeV/c)^2$ at t = -1 $(GeV/c)^2$, and will be slightly momentum-dependent. This resolution should be sufficiently narrow to observe any structure associated with a turn-over of the differential cross section below t = -0.1 $(GeV/c)^2$ as well as the minimum or "break" near t = -0.6 $(GeV/c)^2$. The size of the MWPC array determines the cutoff value of t, which is $|t_{max}|$ = 2.3 $(GeV/c)^2$ for π^o's, and $|t_{max}|$ = 1.2 $(GeV/c)^2$ for η's.

We expect to accumulate between 1- and 2 $\times$ 10^5 $\pi^o n$ events at each momentum and a smaller number of ηn events dependent upon the relative π^o and η cross sections, since these will run concurrently.

In order to estimate the running time required, we have made an empirical prediction of the high energy $\pi^o n$ cross sections based upon the data of Mannelli et al.[3]

$$\frac{d\sigma}{dt}\,(t = 0) = 1590\ p^{-0.84}$$

$$\sigma = p^{0.84}\ \frac{1590}{1.92\ \ln p}\left[1 - e^{-0.384\ \ln p}\left(1 - \frac{1.92\ \ln p}{2.1 + 1.92\ \ln p}\right)\right],$$

with p in GeV/c, $d\sigma/dt$ in $\mu b/(GeV/c)^2$ and σ in μb. These predictions are in reasonable agreement with much more detailed, model-dependant predictions by Barger.[5]

The differential cross-section at 100 GeV/c, as predicted by Barger, is shown in Fig. 2. The rapid fall-off of the distribution at large t values necessitates a high-statistics experiment. The breakdown into expected number of events per t interval is given in Table I. Even with 2×10^5 total events, we only expect $\approx$ 100 events/0.1 $(GeV/c)^2$ near the "break" at $t = -0.6\ (GeV/c)^2$, and only $\approx$ 15 events/0.1 $(GeV/c)^2$ at $t = -1.0\ (GeV/c)^2$.

In addition, the high statistics at low values of t allow us to look for structure near t = 0. By narrowing our γ-γ opening angle cut, the t resolution would be less than $\pm$ .001 $(GeV/c)^2$ at $t = -.001\ (GeV/c)^2$, and still result in about 1000 events in the interval between t = 0 and $t = -.002\ (GeV/c)^2$. This is shown in Table II, along with the expected resolution and statistics for different opening-angle cuts at small values of t.

At 100 GeV/c, we predict a $\pi^o n$ cross section of about 3 μb. With an incident pion flux of $10^6\ \pi^-$/pulse and a 3-ft.-long liquid hydrogen target, we expect 10 $\pi^o n$ events/pulse. Based upon the experiment of Mannelli et al.,[3] we expect a trigger/event ratio of 3:1. This data rate of 30 trigger/pulse will

Table I. Expected number of events per t interval for the $\pi^- + p \to \pi^0 + n$ differential cross section at 100 GeV/c. These estimates are based upon Barger's predictions,[5] as shown in Fig. 2, and assume a total of 200 K events.

-t interval $(GeV/c)^2$	$(d\sigma/dt)_{average}$ for interval $\mu b/(GeV/c)^2$	Number of events per interval
0 - .1	24	128 000
.1 - .2	10	53 400
.2 - .3	2.8	14 900
.3 - .4	.58	3 100
.4 - .5	.080	430
.5 - .6	.020	110
.6 - .7	.014	75
.7 - .8	.010	53
.8 - .9	.007	37
.9 - 1.0	.004	21
1.0 - 1.1	.002	10
1.1 - 1.2	.001	5
$\int_0^{-1.0} \frac{d\sigma}{dt}\, dt$	3.75 μb	200 000 total

Table II. Resolution in t near t = 0. At 100 GeV/c, the resolution in t near t = 0 is given by $\delta t \simeq .06\sqrt{t}$, for a γ-γ opening-angle cut which accepts 50% of the events. For a narrower cut, accepting 15% of the events, the resolution becomes $\delta t \simeq .024\sqrt{t}$. These resolutions are tabulated below, along with the expected numbers of events per t interval.

t interval $(GeV/c)^2$	Central value of t $(GeV/c)^2$	Opening angle cut (%)	Resolution in t $(GeV/c)^2$	Number of events in t interval
0 - .02	.01	50	± .006	32 K
0 - .01	.005	50	± .004	16 K
0 - .005	.0025	50	± .003	8 K
0 - .005	.0025	15	± .0012	2.4 K
0 - .002	.001	50	± .0019	3.2 K
0 - .002	.001	15	± .0008	1.0 K

be within the capacity of our MWPC readout system.

During 100 hours of running, at 600 beam pulses per hour, we would accumulate 6×10^5 total $\pi^o n$ events at 100 GeV/c. After the 50% opening angle cut, plus other smaller cuts on the data, we would have about 2×10^5 events in the differential cross section distribution. We expect that 100 hours will be the average running time for each of the four momenta.

We also intend to run for about 50 hours in a "poor geometry" configuration; that is, at the maximum momentum and the minimum hydrogen-target-to-MWPC distance. For example, at 200 GeV/c, the downstream distance would be only 50 feet. This will allow us to make a survey of final states with $> 2\gamma$'s. Such a running configuration proved to be very fruitful[6] at 10 GeV/c, especially for the $\pi^o\gamma$ and $\pi^o\pi^o$ final states. Besides the interesting physics in the multi-γ final states, such data are very valuable in calculating backgrounds for our 2γ data. These backgrounds are a result of multi-γ events appearing to be 2-shower events when one or more γ's escape detection.

In all we request 500 hours of running time. This running time estimate assumes that the beam will consist of a 1-sec-long flat-top spill every six seconds, plus an rf duty cycle of 10 or less.

We estimate that the time needed for tuning and setup will be approximately the same as for the actual run, namely 500 hours of testing.

If higher energy beams and additional running time become available, we would be prepared to measure points at 300 and 400 GeV/c. This would involve the use of a longer liquid hydrogen target, as well as a longer H_2-target-to MWPC-array distance.

Also, if the charge exchange measurement has not been undertaken at Serpukhov by the time of this proposed experiment, or if it has been run but shows inconsistancies with the current results at 18 GeV/c, we would propose to measure an additional point at 20 GeV/c and request 100 hours additional running time. This point would be run without the downstream magnet in place, and with a reduced beam intensity.

The experimenters listed above have been working together on three separate experiments over the past two years, all of which have involved the measurement of neutral η and π^o final states. Our data analysis system, which is compatible with this proposed experiment, is currently operational.

Apparatus

All of the scintillation counters, the liquid hydrogen target, and the multi-wire proportional chambers will be provided by LRL.

We would prefer that the beam Cerenkov counter be provided by NAL, as it would be a permanent NAL facility. However, we will consider designing and building it ourselves, in collaboration with NAL physicists, regarding it as an NAL facility.

We request that the downstream bending magnet be provided by NAL. We do not know whether a magnet of this size would be readily available at NAL, or whether it would have to be constructed especially for this experiment. Even if the latter is true, it seems likely that such a magnet could be used to advantage in subsequent NAL experiments. We estimate $190 K for the magnet cost, $100 K for the power supply cost, and a power requirement of 1.4 megawatts.

We require helium bags for most of the distance between the hydrogen target and the MWPC array. This distance will be 200 ft. at 200 GeV/c, and the cross-sectional size of the bag must increase from several square inches near the hydrogen target to 40 inches by 40 inches at the MWPC array. We also require helium bags (or vacuum pipes) in the incident beam line. It would be much more convenient if these helium bags, and the means of repairing them, were provided by NAL.

The fast logic, Chronetics-type, electronics will be provided by LRL.

References

1. G. Höhler, J. Baacke, H. Schlaile, and P. Sonderegger, Phys. Letters 20, 79 (1966).

2. P. Bonamy, P. Borgeaud, C. Bruneton, P. Falk-Vairant, O. Guisan, P. Sonderegger, C. Caverzasio, J. P. Guillaud, J. Schneider, M. Yvert, I. Mannelli, F. Sergiampietri, and L. Vincelli, Phys. Letters 23, 501 (1966).

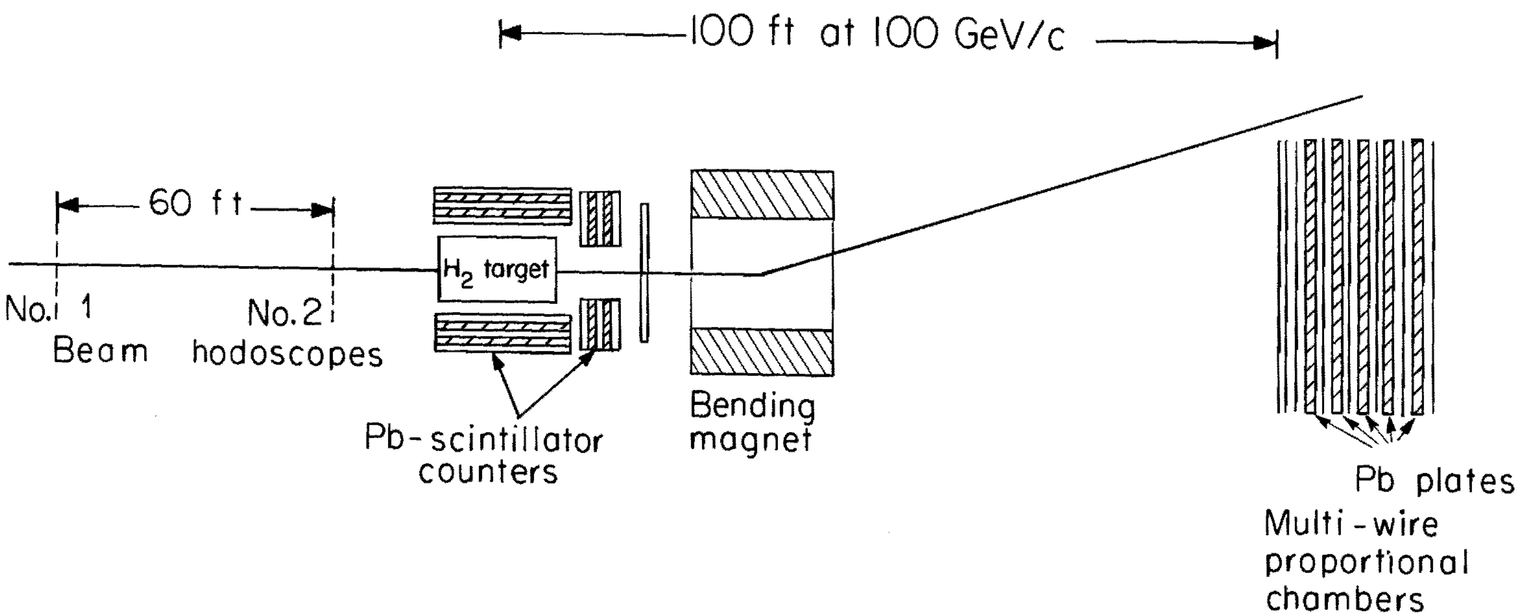
3. I. Mannelli, A. Bigi, R. Carrara, M. Wahlig, and L. Sodickson, Phys. Rev. Letters 14, 408 (1965).

4. S. J. Lindenbaum, Proc. πN Scattering Conf., University of California, Irvine (1967).

5. Vernon Barger, private communication.

6. E. I. Shibata, D. H. Frisch, and M. A. Wahlig (to be published in Phys. Rev. Letters); M. Wahlig, E. Shibata, D. Gordon, D. Frisch, and I. Mannelli, Phys. Rev. 147, 941 (1966); E. Shibata and M. Wahlig, Phys. Letters 22, 354 (1966); M. A. Wahlig, E. Shibata, and I. Mannelli, Phys. Rev. Letters 17, 221 (1966).

Experimental arrangement



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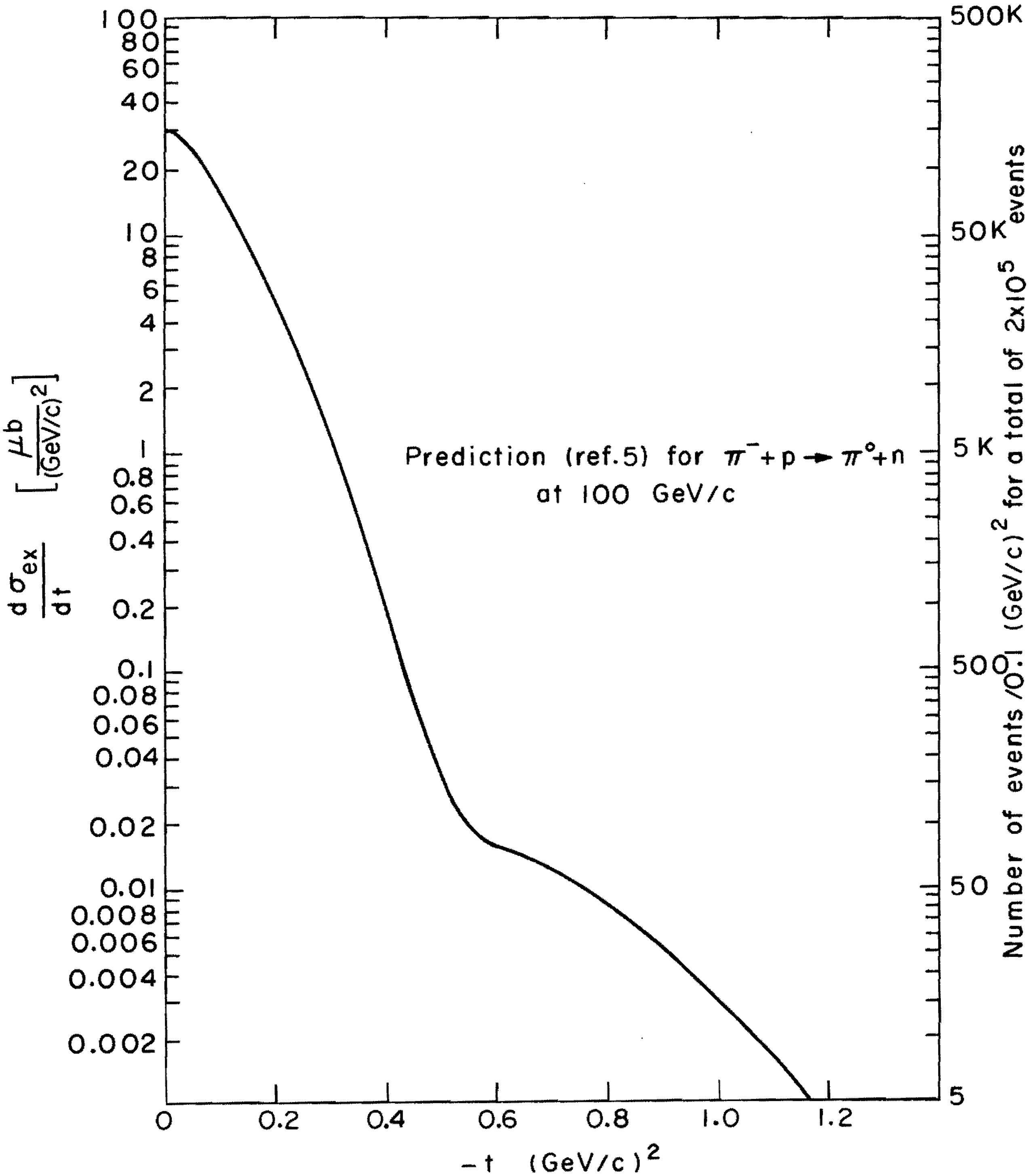

XBL7010-4000

June 26, 1970

Letter of Intent

To Submit a Proposal to Measure the Charge Exchange Reactions $\pi^- + p \rightarrow \pi^0 + n$ and $\pi^- + p \rightarrow \eta + n$ at High Energies.

Michael Wahlig, Andris Skuja, Morris Pripstein, Jerry Nelson, Ivan Linscott, Robert Kenney, Orin Dahl, and Roger Chaffee, LRL Berkeley.

We propose to measure the differential cross sections in the forward direction for the reactions $\pi^- + p \rightarrow \pi^0 + n$ and $\pi^- + p \rightarrow \eta + n$. Measurements will be made at four momenta spanning the newly-accessible energy region, typically at 50, 100, 150, and 200 GeV/c. These measurements will include four-momentum transfers from $t = 0$ out to $t \simeq = -1$ $(\mathrm{GeV/c})^2$.

The charge-exchange reaction is one of the most important measurements to be made in this new energy region, for at least two reasons. First, the simplicity of its description in terms of the exchange of a single Regge pole allows the most direct experimental check on the validity of Regge theory at these high energies. This statement also applies to the $\pi^- p \rightarrow \eta n$ reaction. In the simple Regge model, the forward $\pi^0 n$ reaction proceeds via ρ exchange, the ηn via A_2 exchange.

Secondly, the rate of decrease with energy of the 0 deg charge-exchange cross section is a sensitive measure (via the optical theorm) of the rate of approach of the $\pi^- p$ and $\pi^+ p$ total cross sections, and is thus a measure of how close we are to "asymptopia."

$$\left[\mathrm{Im}\ A_{ex}\ (t = 0)\right]^2 = \frac{(\Delta\sigma)^2}{32\pi\hbar^2} ,$$

where A_{ex} is the charge-exchange amplitude, and $\Delta\sigma$ is the difference between the $\pi^- p$ and $\pi^+ p$ total cross sections. Using the observation that the real and imaginary parts of the charge-exchange amplitude are approximately equal at 10-to-20 GeV/c, and converting to useful units, we get

$$\frac{d\sigma_{ex}}{dt}\,(t = 0) = 50\,(\Delta\sigma)^2 ,$$

with $d\sigma/dt$ in $\mu b/(GeV/c)^2$ and $\Delta\sigma$ in mb. Let α equal the percentage error in a measurement of the total πp cross section σ, and β equal the percentage error in $d\sigma_{ex}/dt$. In order that the measurement of $\sigma(\pi^- p)$ and $\sigma(\pi^+ p)$ produce the same error in $\Delta\sigma$ as does a measurement of $d\sigma_{ex}/dt$, we must have

$$\frac{\beta}{\alpha} = 2\sqrt{2}\,\frac{\sigma}{\Delta\sigma} .$$

The high energy total $\pi^{\pm}p$ cross section parameterization of Lindenbaum (Proc. of the Irvine Conference on πN Scattering, Dec. 1967) predicts that $\sigma = 23$ mb and $\Delta\sigma = 0.7$ mb at 100 GeV/c. This means that, at 100 GeV/c, a 10% measurement of $\frac{d\sigma_{ex}}{dt}\,(t = 0)$ is equivalent to a 0.1% measurement of both the $\pi^- p$ and $\pi^+ p$ total cross sections.

The NAL beam required for this experiment will be a moderate intensity ($\approx 5 \times 10^5\ \pi^-$/pulse) and moderate resolution ($\Delta p/p \simeq 1\%$) pion beam in the #2 experimental area. It would be desirable to have a Cerenkov counter in this beam to separate the π^-'s from the K^-'s and $\bar{p}$'s. If such a Cerenkov counter will not be available at NAL, we will consider building one ourselves.

The incident beam angle must be known to approximately $\pm$ 0.2 mrad. Assuming the incident beam divergence will exceed this figure, we intend to use two beam hodoscopes to determine this incident angle for each particle.

The general description of the experimental technique will be as follows: The pion beam will enter a liquid hydrogen target ($\simeq$ 3 ft. long) which will be surrounded by anticoincidence counters. The downstream anticounters will veto only charged particles; the side anticounters will consist of Pb-scintillator sandwiches, and will veto γ's as well as charged particles. The downstream γ's will be converted in an array of multi-wire proportional chambers (MWPC) separated by Pb plates. This distance between the hydrogen target and the MWPC array will be varied as a function of incident beam momentum; a typical distance is 100 feet at 100 GeV/c.

The MWPC array will consist of approximately 11 chambers, each about 1 meter by 1 meter in area with both X and Y readout. The first few chambers will not be separated by Pb plates, but will be used for further rejection of charged particles. The total thickness of the Pb sheets separating the remaining chambers will be ≈ 4 radiation lengths.

We expect a resolution in the γ-γ opening angle of $\simeq 2$ to 3%, which should provide a very clean sample of π^o's and η's. The resolution in t is expected to be $\simeq \pm .005\ (\text{GeV/c})^2$ at $t = -.005\ (\text{GeV/c})^2$, and $\pm .05\ (\text{GeV/c})^2$ at $t = -1.0$ GeV/c$)^2$.

We expect to accumulate at least 10^5 $\pi^o n$ events at each momentum and a smaller number of ηn events dependent upon the relative π^o and η cross sections, since these will be run concurrently.

In order to estimate the running time required, we have made an empirical prediction of the high energy $\pi^o n$ cross sections based upon the data of Mannelli et al. (Phys. Rev. Letters 14, 408 (1965)):

$$\frac{d\sigma}{dt}\ (t = 0) = 1590\ p^{-0.84}$$

$$\sigma = p^{-0.84}\ \frac{1590}{1.92\ \ln p} \left[1 - e^{-0.384\ \ln p} \left(1 - \frac{1.92\ \ln p}{2.1 + 1.92\ \ln p}\right)\right] .$$

These predictions are in reasonable agreement with much more detailed, model-dependent predictions by Barger (private communication).

At 100 GeV/c, we predict a $\pi^o n$ cross section of about 3μb. With an effective incident pion flux of 3×10^5 π^-/pulse and a 3-ft.-long liquid hydrogen target, we expect 3 $\pi^o n$ events/pulse. Based upon the experiment of Mannelli et al, we expect a trigger/event ratio of 3:1. This data rate of 10 triggers/pulse will well within the capacity of our MWPC readout system.

At 600 beam pulses/hr. it will take 50 hours to accumulate these 10^5 $\pi^o n$ events at 100 GeV/c. Taking this to be an average estimate of the running time for each of our four momenta, and putting in a contingency factor of 2, we will request 400 hours of running time.

This running-time request assumes that the beam will consist of a 1-sec-long flat top spill every six seconds, plus an rf duty cycle of 10. The limitation in our event accumulation rate is the instantaneous beam rate, since $\approx 10\%$ of the beam will interact in the H_2 target and load-up the MWPC array. Our data rate could easily accommodate an improvement of a factor of three in the rf duty cycle, resulting in three times as many $\pi^o n$ events.

If higher energy beams and additional running time become available, we would be prepared to measure points at 300 and 400 GeV/c. This would only necessitate the use of a longer liquid hydrogen target, plus a longer H_2-target-to-MWPC-array distance.

Also, if the charge-exchange measurement has not been undertaken at Serpukhov by the time of this proposed experiment, or if it has been run but shows inconsistancies with the current results at 18 GeV/c, we would propose to measure an additional point at 20 GeV/c and request 100 hours additional running time.

The experimenters listed above have been working together on three separate experiments over the past two years, all of which have involved the measurement of neutral η and π^o final states. Our data analysis system, which is compatible with this proposed experiment, is currently operational.