NAL PROPOSAL No. 172

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Summary

We propose a 50-100,000 photo exploratory exposure of the 14' BC filled with ~30% Neon, 70% H_2, to a broad band $\bar{\nu}$ beam produced by whatever intensity ($\gtrsim 10^{12}$ IP/pulse and energy ($\gtrsim$ 200 GeV) external proton beam is initially available. The Ne-H_2 mixture permits ~10 x higher event rate than pure H_2; also direct detection of γ, K_2^o, n; better $\mu^\pm$, $e^\pm$ identification and the possibility of coherent production reactions from the nucleus as a whole as well as incoherent reactions from both neutrons and protons. The event rate vs. $E_{\bar{\nu}}$ and q^2 will be measured to ~130 GeV permitting (in comparison with HBC experiments) estimate of the A dependence of σ_T, and (given crude flux estimates) tests of scaling and locality in $d^2\sigma/dE_{\bar{\nu}}dq^2$ and σ_T

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as well as comparison of σ_T on n and p and of these with corresponding ν cross sections. Cross sections, particle momenta, invariant mass and angular correlation spectra will be measured for dominant channels permitting crude tests of $\Delta I = 1$, $\Delta I = 1/2$, $\Delta S = \Delta Q$, $\Delta S \neq 2$ rules. New particles and phenomena will be searched for.

Introduction

The physics interest in extending bubble chamber studies of $\bar{\nu}$ interactions to the energies and momentum transfers accessible at NAL has been extensively discussed in several NAL summer studies and previous proposals for $\bar{\nu}$ (31A), ν (9B, 28, 44A, 45A, 53A) and d_2 or TST (20, 42) exposures. See also Llewellyn Smith (SLAC-PUB 958 May 1971 and Physics Reports) for a recent summary of, and references to, the theoretical literature, experimental results to date, and exciting expectations for NAL.

It is clear that NAL data on $\bar{\nu}$ as well as on ν interactions will be crucial to our understanding of the weak interactions and of the structure of leptons and hadrons. Such data may possibly reveal new classes of phenomena and particles such as intermediate bosons, shadow particles, heavy leptons, quarks, and monopoles. Single strange particle production (inverse hyperon muonic decay) should proceed only in $\bar{\nu}$, not ν beams if the $\Delta S = +\Delta Q$ rule remains valid at NAL energies and momentum transfers, e.g. $\bar{\nu}n \rightarrow \mu^+ (\Sigma^-$ or $Y^{*-})$ but $\nu n \not\rightarrow \mu^-(\Sigma^+$ or $Y^{*+})$. $\Delta S = 2$ transitions (e.g. $\bar{\nu}p \rightarrow \mu^+\Xi^0$) may be more accessible to the $\bar{\nu}$ already associated with strange baryons (rather than the ν associated with strange antibaryons, e.g. $\bar{\Lambda} \rightarrow \bar{p} + \mu^+ + \nu$). Thus the most exciting new phenomena could well show up only in $\bar{\nu}$ exposures. Comparison of ν and $\bar{\nu}$ inclusive spectra, topological and reaction cross sections, etc., permits measurement of W_3, tests of $\Delta I = 1$, $\Delta I = 1/2$ rules, etc., and further tests of models of the weak interactions (scaling, locality, current-current form, etc).

For preliminary exploration of such an exciting new domain it is clear that within its cross section sensitivity, the bubble chamber has no current rival: each outgoing charged track's sign, momentum, direction and ionization are measureable with nearly 4π detection efficiency and the event vertex is visible with better than millimeter spatial resolution.

Neon-hydrogen mixtures offer advantages over pure H_2 or D_2 of ~10x higher statistics, better neutral particle and electron detection, better muon identification, complementary recoil baryon polarization analysing power and the possibility of coherent or diffraction dissociation reactions on the nucleus as a whole as well as incoherent reactions on either neutron or proton. Pure H_2 offers compensating advantages, of course, e.g. single proton targets, and higher charged track measurement precision. Both neon-H_2 and pure H_2 runs should be made early as they are in part complementary and their comparison is of great interest.

The event rate, which may be beam limited initially, should be nearly an order of magnitude greater in H_2-Ne (e.g. 1/3 to 1/2 neon) than in pure H_2. Thus an exposure (e.g. 50-100K pictures) at a few times 10^{12} interacting protons/pulse still gives reasonable numbers of expected $\bar{\nu}$ events for a first look: ~1 event/36 photos or order of 1500 to 3000 events in 50-100K photos. (Previous ν-H_2, $\bar{\nu}$-H_2 and ν-Ne proposals were considerably more optimistic than this.)

In this proposal we recapitulate briefly the physics expectations of this experiment. Table 1 shows preliminary event rate estimates.

Physics

1) Total Cross Section

Because neutral particles (γ, K_2^0, n) are directly detected in the Ne-H_2 mixture and their energy measured, the total event rate vs. $E_{\bar{\nu}}$ can be directly measured up to $\gtrsim$130 GeV (for $\gtrsim$200 GeV protons, see Table 1). Independently of knowledge of the $\bar{\nu}$ flux, this information will permit an estimate of n vs. $E_{\bar{\nu}}$ where $\sigma_{Ne} = \left(\frac{\sigma_p + \sigma_n}{2}\right)A^n$. That n may not be exactly 1, perhaps in analogy to the $n < 1$ dependence of total hadronic photoproduction cross sections on atomic number, alone justifies a Neon exploratory run. Again independently of flux knowledge $\sigma_n \equiv (\sigma_T$ on neutrons) can be compared with σ_p (as a function of $E_{\bar{\nu}}$). Some quark models predict $\sigma_p = 2\sigma_n$ for example, while $\sigma_p = \sigma_n$ would be expected if diffraction-like processes dominate. σ_p and σ_n can be separately estimated in neon by comparing numbers of events with net charge 0, +1, +2, etc.

Given estimates of the $\bar{\nu}$ flux (or up to ~30 GeV determining the flux from the elastic ($\bar{\nu}p \rightarrow \mu^+n$) event rate assuming its cross section known) we can see whether scaling holds, i.e. $\sigma_T(\bar{\nu})$ = const * $E_{\bar{\nu}}$ and if so up to what energy. Deviations from this simple law may indicate a non-local weak interaction, e.g. mediated by a vector boson. Comparison with

$\sigma_T(\nu)$ is also of great interest of course. If diffraction-like processes dominate $\sigma_{\nu n} = \sigma_{\nu p} = \sigma_{\bar{\nu} n} = \sigma_{\bar{\nu} p}$, while some parton models predict $\sigma_{\nu p \text{ or } n} = 3\sigma_{\bar{\nu} p \text{ or } n}$.

2) Inclusive Muon Spectra

This experiment permits study of deep inelastic processes ($\bar{\nu} + n \rightarrow \mu^+$ + anything) with ~10x higher event rate, better muon identification and better event energy determination (including neutrals) than a pure HBC allows. Note also that the μ^+ is not affected by its passage through nuclear matter and because $E_{\bar{\nu}}$ is measureable also, $d^2\sigma/dE_{\bar{\nu}}dq^2$ can be measured (given crude flux estimates) independently of possible secondary nuclear interactions of the hadrons. Thus further tests of scaling (q^2 dependence, etc), locality, etc., will result.

The lepton-hadron plane angle may be smeared by secondary nuclear interactions scrambling the hadrons, but the scrambling may well be small enough because of the high proportion of interactions near the nuclear surface and not too large secondary interaction probability that a useful check of the current-current form should result.

Within the framework of the current-current interaction form, only three combinations of structure functions are measurable if the final lepton polarization is not observed. Of the three corresponding form factors, W_3 due to V,A interference can be measured only by comparing ν and $\bar{\nu}$ inclusive spectra.

3) Topological and Channel Cross Sections-Inverse Leptonic-Decays

As in CERN HLBC experiments at lower energies, statistical (at least) separation of the dominant inelastic final states should be possible, yielding channel cross sections and for the copious channels gross characteristics such as invariant mass, angular, momentum and momentum transfer distributions, angular correlations, etc.

Tests of $\Delta I = 1$ relations among inverse leptonic decays of baryon states, e.g. $\bar{\nu}p \to \mu^+\Delta^o$, $\bar{\nu}n \to \mu^+\Delta^-$, etc. should result if their cross sections remain of the same order as the elastic cross section as at lower energies. Corresponding tests of $\Delta I = 1/2$ rules may result if strange particle production is copious enough (see below).

At the very least this experiment will permit exploratory studies of the dominant inelastic channels with ~10x better statistics, sensitivity to outgoing neutrals (γ, K_2^o, n), and clearer μ and $e^{\pm}$ identification. The information will be useful for planning future experiments and for comparison with HBC ν and $\bar{\nu}$ runs.

4) Inverse Hyperon Leptonic Decays

Inverse hyperon leptonic decays have been observed in the CERN HLBC $\bar{\nu}$ experiments at lower energies. Since our experiment should yield at least as many total $\bar{\nu}$ interactions as the CERN $\bar{\nu}$ HLBC experiments we expect to observe some examples of $\bar{\nu}p \to \mu^+ + (\Lambda \text{ or } \Sigma^o \text{ or } Y^{*o})$, $\bar{\nu}n \to \mu^+ + (\Sigma^- \text{ or } Y^{*-})$

inverse muonic decays. In most of these reactions γ detection is important, and necessary for tests of $\Delta I = 1/2$ rule.

5) Inverse Meson Leptonic Decays, Coherent Reactions

Our experiment will also be sensitive to sufficiently copious corresponding inverse leptonic decays of mesons, e.g. $\bar{\nu} + Ne \rightarrow Ne + \mu^{+} + (\rho^{-}$ or A_1^{-} or B^{-}, etc). The possibility that these reactions may be coherently amplified in the neon nucleus (as well as the ~10x greater statistics and γ detection) is a further reason for early $\bar{\nu}$-Ne runs.

6) New Particles

The ~10x higher event rate for this experiment over HBC's, also better $\mu^{\pm}$, $e^{\pm}$ and neutral particle detection are crucial, of course, for new particle searches. Note $W^{-} \rightarrow e^{-}\nu$, $W^{-} \rightarrow \pi^{-}\pi^{0}$, heavy lepton $\rightarrow \mu + \gamma$ or $\rightarrow e + \gamma$, for example.

7) Neutral Currents

The short interaction length for fast neutrons in Ne-H_2 (~1.5m vs. ~8m in H_2) gives some hope of statistically separating neutron stars from muonless neutrino interactions if the latter are as unexpectedly copious as rumors from the CERN HLBC ν experiments suggest. The 15' BC has less steel and copper near the middle of the chamber in the beam region and so should afford clearer separation than does Gargamelle. Note also that interactions of $\bar{\nu}$ yeld more neutrons than do ν interactions (e.g. $\bar{\nu}p \rightarrow \mu^{+}n$ while $\nu n \rightarrow \mu^{-}p$). Thus comparison of ν and $\bar{\nu}$ exposures will be useful in interpreting the muonless events.

Event Rates

We use Nezrick's 1 Nov. 71 ν flux estimate (which assumes 10^{13} interacting protons/pulse at 200 GeV, in a 40 cm long 1 interaction length target, with double horn focussing, and averaged over 2.7m diameter). This predicts 1 event/25 pulses in $20m^3$ of H_2, assuming $\sigma_T = 0.8 \times 10^{-38}$ $cm^2 \times E_\nu$(GeV) as measured at CERN up to ~10 GeV (and as expected if scale invariance holds and no cutoff, e.g. due to an intermediate vector boson causes saturation).

To obtain the $\bar{\nu}$ in neon event rate we scale by factors: $1/3 \approx \bar{\nu}/\nu$, $1/5 = 2 \times 10^{12}/10^{13}$ protons, $10 \approx$ (H_2-Ne density)/(H_2 density) and thus we expect ~ 2/3 x 1 event/25 pulses in $20m^3 = \pi \cdot 2.7 \times 2.35$ of chamber fiducial volume, i.e. ~ 6 tons of mixture. Hence we predict approximately 1 evt/36 pulses ≈ 27 evts/hr. at 4 sec. repetition rate. Therefore 50K pictures would yield roughly 1500 $\bar{\nu}$ interactions in H_2-Ne. This can be compared with ~ 150 events predicted in pure H_2 and with ~ 4500 ν interactions predicted in H_2-Ne (or 450 in pure H_2). Note that earlier proposals are considerably more optimistic than this. We, too may be optimistic in assuming $\sigma_T(\bar{\nu}) \approx \sigma_T(\nu)$ in view of the CERN HLBC preliminary results indicating $\sigma_T(\bar{\nu}) < \sigma_T(\nu)$; hopefully we are pessimistic, however, in assuming only 2×10^{12} interacting protons/pulse.

The events would be distributed in energy as shown in Table 1. Nearly all of these events will be useful for exploratory studies and total cross sections estimates and will yield information on deep inelastic processes and various inelastic channels. Of course the upstream half or so of these events, i.e. those from $\sim$ 1/3 the chamber volume, will have more of the chamber available for outgoing track identification. Information from these events will provide calibration of muon (and other track), identification techniques and total energy, q^2, etc., measurement techniques.

Why Us?

We have had extensive experience in a variety of bubble chamber experiments in a variety of beams, some using H_2-Ne mixtures in the BNL 80" BC, some using freons and propane-freon mixtures in large HLBC's, some using HBC or DBC's. Some of us participated in various stages of the CERN HLBC ν and $\bar{\nu}$ experiments and/or in other weak interaction HLBC experiments, some in photoproduction experiments using HBC's.

We have operating and well-tested program systems for handling neutral beams, electron reconstruction, π^0 fitting, etc. (Because the μ^+ is expected to carry off on the average $\sim$ 2/3 of the $\bar{\nu}$ energy, the energies of the hadron states produced in $\bar{\nu}$ interactions will normally be in the range where our program systems have been extensively tested.) Our physics analysis programs (plotting, curve fitting, maximum likelihood, Monte Carlo, etc.) are in production and continually being improved. Our scanning and measuring staffs have had experience with large HLBC film and we have struggled to tune optical constants for several large BC's. With the measurement capacities at

Berkeley and Seattle and the very high priority we will put on this experiment we do not anticipate undue trouble measuring rapidly the small number of events expected in this experiment. (Our guess is that it will not come so early as to conflict with our other approved experiments in any case.) We have made contact with groups proposing νNe, $\bar{\nu} H_2$ and νH_2 experiments and anticipate no difficulty in exchanging information, programs and data for comparison. In particular we have tentatively agreed with the Wisconsin group proposing νNe to coordinate our scanning and measuring criteria and procedures in order to be able to compare results on total, topological and inclusive cross sections at an early stage of the analysis. In short we are eager to do this experiment and we are confident that we can produce results in a reasonably short time.

We believe that the results of this experiment will be intriguing enough to justify a massive future effort involving millions of photos, external muon identifiers, higher beam intensity, perhaps narrow band beams.

TABLE 1

Event rate estimates per 100,000 photos, using Nezrick's 1 Nov. 71 ν flux estimates (scaled to 2×10^{12} IP/pulse from 10^{13} at 200 GeV, assuming 40 cm long 1λ target, double horn focussing, averaged over 2.7m diameter). Also assuming $\bar{\nu}/\nu = 1/3$ and $\sigma_T = 0.8\ E_{\bar{\nu}}(\text{GeV}) \times 10^{-38}\text{cm}^2$.

E_ν(GeV)	0-10	10-20	20-30	30-50	50-80	80-130
$\bar{\nu}/\text{m}^2$ GeV	0.3	0.6	0.25	0.04	0.005	0.002
No. evts/10^3 pulses 10^{-38} cm^2	0.7	0.7	0.29	0.11	0.03	0.006
Total No. evts/100,000 ph.	480	950	620	310	130	50
No. Elastic evts/100,000 ph. ($0.6 \times 10^{-38}/2$)	21	21	9			