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AN INTENSE SOURCE OF STRANGENESS

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ON THE FEASIBILITY OF PERFORMING NEUTRINO EXPERIMENTS
AT AN INTENSE SOURCE OF STRANGENESS

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Abstract

Several very important low energy neutrino experiments have been identified and discussed by Kayser and Rosen in these proceedings. We address the possibility of performing some of these experiments in the environment of a kaon factory. To carry out specific analyses, we draw upon the design of existing BNL detectors, the design of experiments that are proposed for an 800 MeV proton driven facility at Los Alamos, and the use of the code NUBEAM developed at CERN. Since in most cases we have not optimized, this is a conservative estimate. We find that many of the desired experiments can be performed with facilities now under discussion.

Introduction

Several important experiments that could be performed with beams of low energy neutrinos were considered by the neutrino subgroup. Boris Kayser and Peter Rosen¹ have prepared an excellent summary of the physics issues, identifying seven major areas of interest. In view of those interests, the conference organizers have asked us to provide a discussion of the feasibility of such experiments at an intense source of low energy neutrinos that one would expect to have in conjunction with a kaon factory. It is not possible for us to respond in the detail that we would wish, nor to discuss the entire range of experiments identified in the article of Kayser and Rosen. However, we hope that we are providing enough detail to convince the reader that a range of important neutrino experiments is feasible. These experiments will provide unique information about the structure of fundamental interactions and therefore constitute an additional justification for the construction of such a facility.

In order to truly discuss the feasibility of any neutrino experiment it is necessary to specify both the neutrino source and the neutrino detector. The specification of the source includes the energy and intensity of the primary proton beam, the construction of the proton target, and the focussing device (presumably a horn) to focus the mesons for increased neutrino flux and, where possible, for neutrino type selection. These factors translate into a neutrino spectrum over the detector. A detector must be specified in order to translate the neutrino flux into a counting rate, and to estimate the kinds and amounts of backgrounds, and to assess the ability of a particular detector to suppress those backgrounds.

In this article, we shall rely upon comparisons with the existing program at Brookhaven and with detailed designs included in the Los Alamos proposal for an intense neutrino source using the existing LAMPF beam of 800 MeV protons as the primary beam on the production target². We also employ the Monte Carlo code NUBEAM that was developed at CERN³. This code reproduces the operating conditions at the Brookhaven AGS and the results from the independent Monte Carlo code LANLNU⁴ that is used in the Los Alamos neutrino facility proposal². Also, a code based on the SLAC EGS Electromagnetic shower code⁵ was used to model the detector.

Turning first to the question of neutrino fluxes and relative counting rates, we have chosen to use $\nu_{\mu e} \rightarrow \nu_{\mu e}$ scattering to compare rates, a nominal 100 micro-amps on target and various horn designs. To specify the calculation of the neutrino fluxes, we refer to Fig. 1. For the low energy case, a horn shape in the decay tunnel is assumed as shown on Fig. 2. For the distribution of pions produced by 800 MeV protons, we believe that the shape is nearly optimal, although some tens of per cent increase may yet be achieved. The variation of neutrino flux with decay channel length is shown on Fig. 3 and the neutrino spectrum is shown on Fig. 4.

Fig. 1. General facility geometry.

For the case of 30 GeV protons, we have used the present BNL two horn configuration. For this configuration, the variation in total neutrino flux and in mean neutrino energy with the length of the decay tunnel are shown on Fig. 5 and the neutrino spectrum is shown on Fig. 6.

Fig. 2. Focussing horn for 800 MeV protons.

Fig. 3. Flux variation with decay channel length, 800 MeV proton.

Fig. 4. Neutrino energy spectrum for 800 MeV protons.

Fig. 5 Variation of total neutrino flux and the mean neutrino energy with decay tunnel length for 30 GeV protons.

Fig. 6. Neutrino energy spectrum for a wide band beam and 30 GeV protons.

Turning now to counting rate estimates, for the 800 MeV proton case we use the detector design of the Los Alamos National Laboratory proposal.² To be more specific, the detector is shown schematically on Fig. 7. Its parameters are:

Size = 5-m x 5-m x 22-m
 Total aluminum tonnage = 366 T
 Total scintillator tonnage = 136T
 Average density = 0.91 gm/cm³
 Average Rad. length = 38 cm (over all detector)
 Average dE/dx = 1.6 MeV/cm (minimum ionizing)
 Average gamma - conversion length = 49 cm
 Per cent electron energy deposited in scintillators = 30% (visible total energy)

The pions are horn focussed as discussed in the Los Alamos proposal. Although the focussing is wide band, the energy spectrum of interacting neutrinos tends to mimic a narrow band beam. This interacting spectrum is roughly ± 30% wide.

Fig. 7 Schematic of a module of the detector used for rate estimates with 800 MeV protons.

To make estimates for the case of 30 GeV protons, since the counting rates increase with the neutrino energy and beam associated backgrounds originating in inert material also increase dramatically, we eliminate the inert material, resulting in a design that essentially matches the existing Perm-Brown-Tokyo-BNL detector. For narrow band beam counting rate estimates, we have assumed narrow band beam focussing of the pions with a mean energy of 1.5 GeV and a spread of $\pm 15\%$. This is a very conservative narrow band beam design.

In the high energy case, an electron energy cut is set at 200 MeV; for the low energy case the cut is at 75 MeV. The data are summarized in Table I.

As one can see from the rates quoted in the last column, there is the possibility of a great gain in statistics over the LAMPF facility in going to a kaon factory. However, one must consider also background suppression and the ability to extract the relevant

		$\langle T_p \rangle$ GeV	ν_μ Flux #/cm ² -s	Narrow Band Horn Efficiency	$\langle E_{\nu_\mu} \rangle$ GeV	Relative $\nu_{\mu e} + \nu_{\mu e}$ Rate	Conditions
BNL Wide Band Horn	scaled from measurement	30	3×10^7	----	1.98	----	BNL Geometry
	MUBEAM		1.58×10^7				
Estimated BNL Narrow Band with MUBEAM		30	1.1×10^6	1/15 ^a	3	4.8	BNL Geometry
LAMPF II Ideal ^b Wide Band (0°-45°)		30	2.4×10^8	----	.94	----	50 m decay tunnel 20 m Fe shield
LAMPF II Ideal ^b Narrow Band (0.57°-3.44°)		30	1.5×10^7	1/15	1.56	32	"
LAMPF II experimental area: MUBEAM simulation		30	4.8×10^7	1/15	2.5	80	"
Los Alamos Neutrino Facility Proposal	LANLNU	0.8	1.0×10^7				12 m decay channel
	MUBEAM ^c		1.87×10^7	----	.16	1	9 m Fe shield

^a Based on experience and estimates for improved BNL two horn system.

^b Reference 6 with target effects included.

^c Low energy target effects (proton and pion energy loss) not included. This is 2x too high. LANLNU results taken as normalization.

Table I - Fluxes and relative ν_μ -e elastic count rates.

physics. It is worth noting that the $\langle E_\nu \rangle$ from a kaon factory can be tuned to a lower energy if a specific experiment requires it. However, beam associated backgrounds are a function of the proton energy as well as the neutrino beam characteristics. These backgrounds include high energy neutrons, which necessitate additional shielding between the source and the detector, and electron neutrinos produced in time by kaon decays. Many methods of cleaning up the neutrino beam will involve some decrease in the useful flux, so a neutrino physics program will benefit from the highest possible proton currents. For some specific experiments variable proton energy will be useful.

As Kayser and Rosen point out, $\nu_{\mu e}$ scattering is most interesting if one can measure a y -distribution. To do so one requires a measurement of the energy of the scattered electron and enough statistics to regress out the shape of the interacting neutrino spectrum.

In Fig. 8 we show a Monte Carlo reconstruction of y -distributions for the 800 MeV proton $\langle E_\nu \rangle = 170$ MeV case and for the 30 GeV proton $\langle E_\nu \rangle = 1.5$ GeV case. In the latter example the narrow band beam focussing condition described above is assumed. Based on current BNL data, π^0 backgrounds appear tractable and the random error per event is greatly reduced in the narrow band case. Some complimentary angle information is also available if the detector has sufficiently fine resolution.

Fig. 8. y reconstructed by energy only vs. y actual.

Quoting from the Los Alamos National Laboratory proposal, with 100 micro-amps of proton current and 500 tons of detector, one should obtain a 1 per cent (± 0.002) measurement of $\sin^2 \theta_w$ in 100 running days.

Another measurement that was singled out for study is the exclusive ν_μ to ν_e oscillation channel at low mixing probability as well as small Δm^2 . At 800 MeV, that will be limited by statistics to a few times 10^{-6} . To achieve such a low level, it is necessary not only to suppress cosmic ray backgrounds, but to take advantage of the lack of beam related π^0 at those neutrino energies. It will also be necessary to subtract the electron events from electron neutrinos produced in π_{e2} decay. The latter will be possible since the spectrum of ν_μ peaks at over twice the energy of the ν_e spectrum.

Since the measurement will be dominated by the ten to the minus four π_{e2} decay, counting rate is crucial, if backgrounds are under control, since limiting values improve as the fourth root of the total counts. For this study, an optimum neutrino energy may well be below the maximum achievable at a kaon facility and a narrow band beam will be crucial.

Several neutrino-nucleus experiments were also singled out for study. On Fig. 9 we display inclusive cross-sections for charged current reactions on Carbon as a function of neutrino energy⁷. Clearly counting rates can be expected to rise as the mean

Fig. 9. Total neutrino cross sections $\sigma(\nu)$ versus neutrino energy ν using the standard model.

neutrino energy rises above 200 MeV. Backgrounds related to a particular exclusive signal (a high energy decay gamma ray, for example) must be considered in establishing the optimum energy of the neutrino beam. In fact, different energy dependencies of signal and background may be necessary to measure exclusive cross-sections with sufficient accuracy to use the nucleus as a filter for spin and isospin characteristics of the weak currents.

Since background suppression always depends on the detector and since targets and detectors are one in neutrino physics, we cannot discuss real sensitivities here. In Table II, we simply list the counting rates estimated for 800 MeV protons with the detector described above (Fig. 1) and the neutrino flux of Fig. 5. These counting rates will change with neutrino energy, flux, detector composition and efficiency and are given here as illustration of the possibility of performing such experiments.

$N(\mu^- N^{12})$	195 events/ day
$N(\mu^+ B^{12})$	7 events/day
$N(\nu_\mu C^*)$	114 events/day

Table II - Selected counting rates.

It is clear to us from the discussion above that the physics described by Kayser and Rosen¹ is definitely accessible with a low energy neutrino facility that can be part of any medium energy intense source of kaons and should form a substantial part of the justification for such a facility.

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