A CONCEPTUAL DESIGN FOR A K_{0L} TAGGED NEUTRINO BEAM

L. Nodulman
Argonne National Laboratory, Argonne, Illinois 60439

A neutral channel at a 20-TeV fixed-target proton accelerator could be used to provide a tagged neutrino beam using K_{0L} decays. Muon and electron neutrinos and antineutrinos are identified and energy tagged up to above 2 TeV, allowing excellent systematics and good statistics in studying their interactions. The precise measurement of cross sections for charged-current and neutral-current interactions provide an excellent check for deviations from the standard model of electroweak interactions. Without the benefit of detailed Monte-Carlo studies needed for a specific proposal, we show a conceptual design demonstrating the feasibility of such a program.

K_{0L} Production

We assume that the accelerator spills 2×10^{14} protons over 100 sec during a 300 sec cycle. Taking a 50% allocation of this conservative intensity gives 10^{12} protons/sec to be targeted on one interaction length of Be. A forward cone of half angle 5×10^{-5} rad is taken for the K_{0L}'s and is also considerably populated by neutrons. An extrapolated yield of 4×10^{-4} K_{0L}/proton gives 4×10^{8} K_{0L}/sec. If a higher proton intensity were available, a smaller solid angle would simplify the tagging system. An overall plan of the system is shown in Fig. 1.

The residual primary beam and produced charged particles should be quickly swept out. This can be accomplished with say 250 T m over the first 50 m. Decay products from K_{0s} need to be removed. The K^0_s 2.7 cm decay length gives 53.5 m/TeV. Since production drops off rapidly above 6 TeV, conventional magnet (~ 1T) sweeping for 1600 m, or 5 decay lengths at 6 TeV, should suppress K_{0s} background. The channel radius at the end of the sweeping region of 1.15 km is 8.3 cm.

Decay Volume

The maximum decay angle for a 1 TeV product from $K_{0L} \to \ell\pi\nu$ is 2.2×10^{-4} rad and in the decay region the vacuum should expand to include this angle. The 15.54 m decay length for K_{0L} gives 31 km/TeV. Allowing 5% of the 3 TeV K_{0L} to decay gives a 4.65 km long decay region. The falling acceptance with the K_{0L} energy is compensated by the rising neutrino cross section. The average neutrino interaction corresponds roughly to a 4 TeV K_{0L} for an average decay probability of 4% giving about 1.6×10^{7} decays/sec of which 1.06×10^{7} are good channels. This rate, or somewhat higher for backgrounds, should be no problem for a highly segmented tagging system. At the end of the decay region, the vacuum chamber can be cut back from 110 cm radius, allowing decay angles, to 31.5 cm for the neutral channel.

Tagging System Issues

1. Requirements and Desires

A measurement of the charged π and lepton angles from the K_{0L} decay as well as the angle of the neutrino from its interaction vertex provides a 0C fit, with ambiguity, to the K_{0L} decay. It is also essential to identify the lepton and measure the sign of its charge. Any additional energy/momentum measurement removes the ambiguity and provides constraint to remove background π decay neutrinos and neutron dump neutrinos. Given a well predicted energy for the neutrino, the cross-section measurement and neutral current/charged-current separation is systematically very clean.

2. A Possible Tagging System

Our conceptual design for a tagging system has two longitudinal sections. First, those particles coming out of the vacuum at the end of the decay volume are measured, then the charged particles remaining in the channel are magnetically deflected out of the neutron-filled vacuum tank and analyzed. A 200 m tracking length with several conventional short drift PWC planes should measure angles to ±5 μrad allowing the longitudinal decay vertex to be reconstructed to better than ±20 m at the upstream end of the decay volume. A very large aperture 1-kG magnet ~75 cm long and a further 100 m tracking space is sufficient to unambiguously determine the sign of kinematically relevant particles with minimal deflection of particles still in the pipe. At the end of this region the channel radius is 33 cm and the allowed decay product radius for 1 TeV is 117 cm. This annular region is covered by segmented EM calorimetry to identify electrons, segmented hadron calorimetry for π/μ separation and crude energy measurement, and tracking following absorber to identify muons. Reasonable resolution assumptions are $15\%/\sqrt{E}$ (GeV) for the electron, $100\%/\sqrt{E}$ (GeV) for the pion in

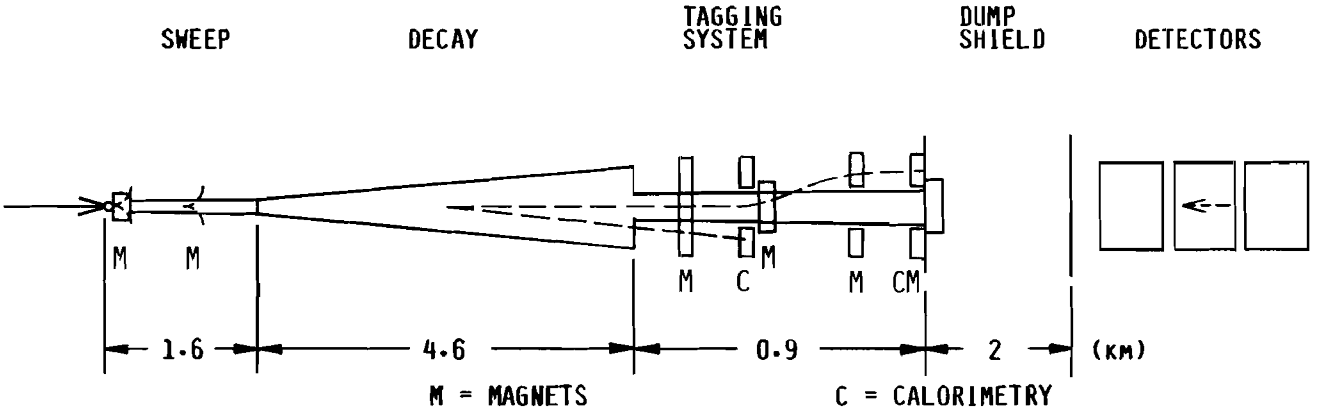

Fig. 1 Layout of a tagged $K_{0L} \to \ell\nu_\ell\pi$ neutrino facility.

calorimeter away from edges, and spectrometer momentum measurement of about 4% at 1 TeV.

The muon tracking is followed immediately by a dipole magnet to deflect charged particles from the channel. An 18 kG magnet with aperture (75 cm)^2, 4.2 m long, will deflect 1-TeV particles 1 m at a point 400 m downstream, where two more such magnets flank the channel and restore the charged particle angles. Note that if you are willing to lose a factor of 4 in rate by cutting the cone angle in half, a factor of 8 is saved in these magnets. Tracking for 150 m followed by calorimeters and muon identification complete the tagging system. For the downstream spectrometer, momentum is measured to 0.04% at 1 TeV, undoubtedly excessive. Restoring the angles allows them to be accurately measured.

3. Calibration, Triggering, Etc.

Normal operation requires a fast $e + \pi$ or $\mu + \pi$ signal in coincidence with a neutrino event. A sample of failed tags should also be recorded along with CP violating decays for calibration. There will be sufficient sample of $K_{0L} \rightarrow \mu\mu$ (~ 0.15/sec) to calibrate muon systems. A considerable opportunity to search for rare K_{0L} decays is afforded, including $K_{0L} \rightarrow \pi^+\pi^-\nu\bar{\nu}$ with one neutrino observed to of order 10^{-6} branching ratio. Measured neutrino energies can be used to check tag predictions. The rate of "dump" and π decay neutrinos should be less than but of the same order as the tagged rate.

4. Constraints and Accuracy

For all cases in this system, the K_{0L} momentum magnitude is unknown and by definition the neutrino energy is taken as unmeasured. This gives a 2 constraint fit to the K_{0L} decay. Assuming the tagging system typically uses several planes of ±200μ drift PWC's (±100 μ/station), the neutrino energy is predicted to about ±6% with the error dominated by the angular measurement. The neutrino interaction vertex is predicted to about ±3 cm transverse.

The Channel Dump/Shield

The large remaining neutron flux must be dumped such that the region behind the dump is kept clear for neutrino detectors. A 2 km shield/dump beginning with 50 m of magnetized iron should reduce the background to neutrino-induced muons in the shield/dump. To reduce this, the last few hundred meters of the shield region could be several feet of iron toroid followed by air. If the shield is well done, one could switch to a beam dump mode of running by simply removing the production target.

Thoughts on Detectors

Typically present-day neutrino detectors have about 5000 g/cm^2 fiducial mass. In this case, for full acceptance at 1 TeV, the radius of the fiducial volume needs to be about 1.7 m. We know of no good way to isolate and measure stiff electrons or positrons in the high multiplicity splash, but using a fine-grained lead plate calorimeter would provide some handle. The energy response of such a device is 30-40% higher for electromagnetic energy than for hadron showers which may give some ability to do distributions for ν_e and $\bar{\nu}_e$ interactions. As with any neutrino beam, a number of detectors can run together.

Rates

If a conservative 50% tagging efficiency is assumed, there are 5.8×10^6 tags/sec. The probability of a charged-current neutrino interaction is given by

$$0.6\times10^{-38}\ \mathrm{cm}^2/\mathrm{GeV} \times 1.3\times10^3\ \mathrm{GeV} \times 5\times10^3\ \mathrm{g/cm}^2$$

$$\times\ 6\times10^{23}\ \mathrm{n/g} = 2.3\times10^{-8}$$

Thus the charged-current rates are 0.04/sec ν_e, 0.026/sec ν_μ, 0.014/sec $\bar{\nu}_e$,and 0.008/sec $\bar{\nu}_\mu$. Given a duty cycle of 1/3, 50% fixed-target allocation, and 2/3 running efficiency, the experiments are live 3×10^6 sec/year. Thus in a year a sample of 1.2×10^5, 8×10^4, 4×10^4, and 2.7×10^4 charged-current events is accumulated for ν_e, ν_μ, $\bar{\nu}_e$, and $\bar{\nu}_\mu$ respectively in each detector. Such a large statistics sample with the tagged systematics should allow a good confirmation of the standard model, or good search for anomalies. A start can also be made at a systematic study of scattering off electrons.