A STUDY OF 40-90 GeV NEUTRINO INTERACTIONS USING A TAGGED NEUTRINO BEAM

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ABSTRACT

A discussion of the significance of inelastic neutrino reactions is followed by a proposal to study the energy dependence of the total cross section and $d\sigma/dq^2$ using a beam of "tagged" neutrinos. The muon energy from K decay is determined to measure the neutrino energy. Reaction rates of ≈ 350 interactions per day can be obtained.

I. USE OF SPARK CHAMBERS FOR NEUTRINO EXPERIMENTS

One of the most exciting prospects for the 200-BeV accelerator is the study of high-energy neutrino and anti-neutrino interactions. This will be a continuation to higher energies of the work begun at BNL and CERN almost a decade ago. Much of this work is planned for the 25-ft bubble chamber, as discussed in the articles in last summer's study program by M. Block and G. Snow.

The question arises as to whether some of the potential neutrino work is not better suited to a counter-spark-chamber approach. Traditionally bubble chambers have proven almost unbeatable for studying qualitative features of reactions on complicated final states. This advantage of the bubble chamber is so clear throughout the recent history of high-energy physics that one who advocates the use of counters and spark chambers is under a heavy obligation to prove "relevance."

Nevertheless exceptions to the rule of bubble-chamber dominance do occur and they are important exceptions. It may be significant to consider them in the study of neutrino interactions at very high energies. We are interested (here) in quantitative answers to several perfectly definite questions concerning the weak interaction. Does the total cross section continue to rise linearly? Does $d\sigma/dq^2$ reflect the apparent point-like quality of the recent SLAC electron scattering data? Is locality a valid concept at these high energies and momentum transfers? It is the assertion here that a counter-spark-chamber experiment designed to obtain precise answers within the limitations of the technique would be a good complement to the obviously valuable bubble-chamber efforts.

There is of course no single clear reason why bubble chambers cannot measure absolute cross sections to 5%, but it will not be easy in the case being discussed because:

1. The incident neutrino spectrum will either have to be calculated or measured by carefully measuring the muon spectrum and K/π ratio vs energy. Hence monitoring of the beam is indirect. If one argues that only the relative energy dependence is crucial and not the absolute cross section, one encounters another difficulty:

2. The energy of the neutrino in a given interaction will have a large uncertainty, since one obtains it by adding up all visible energy in the bubble chamber. The corrections for missing energy in the CERN experiment in propane were $\approx 10\%$. One does not really know the distribution of apparent neutrino energy vs actual energy at all. It is not clear for example that this distribution is symmetric. Hence it can simulate apparent curvature or lack of it in the cross section energy dependence.

3. It has been suggested that normalizing to those channels (such as elastic muon production or single pion production) which are expected to be flat as a function of E_ν can avoid the normalization difficulties of the bubble chamber. This we consider a circular argument which, among other things, normalizes away the W if it exists, unless one compares widely different neutrino energies. Even so one bases the physics learned on several unchecked experimental assumptions.

4. Identification of the muon, when several negative particles leave the chamber, has been and will continue to be a problem.

It appears at the time of writing that a heavy liquid chamber will not be available in the first year or so of operation. Certainly the unique and valuable work to be done with lower energy neutrinos in a hydrogen bubble chamber will create great pressure to use hydrogen and deuterium in the bubble chamber first. No proposals have yet been made for a separate heavy liquid chamber of the size required.

Perhaps the real advantage in the spark-chamber technique is the relative ease with which one can do the experiment.

Here we propose a method for "tagging" the energy of a neutrino, thus hopefully making precision cross-section measurements easier. Tagging might also be used in conjunction with the bubble chamber.

We will first discuss briefly the physics to be studied by this experiment, then the technique of tagging the muons (from K-decays) to determine neutrino energy, and finally the rates to be obtained in a "reasonable" detector. The detailed design of such a detector is left open in this report.

II. INELASTIC NEUTRINO SCATTERING

Total Cross Section

Experiments at CERN[1] using the heavy liquid (freon), and (later) propane, bubble chambers have measured the total cross section for neutrino interactions. The technique involves summing the visible energy in the bubble chamber and then equating this to the neutrino energy. In the propane chamber a correction was made for energy (chiefly γ rays) escaping the chamber. This correction was ~10%. For the freon chamber experiment, the neutrino spectrum was determined only by calculation and was not measured. The total cross section thus determined is shown in Fig. 1. It is seen to follow a linear relationship with energy to ~12 GeV:

$$\sigma_{tot}^{exp} \sim 0.6 \times 10^{-38}\ E_\nu \text{ (in GeV) cm}^2 .$$

Scattering from a point particle would give the cross section

$$\sigma_{tot} \sim \frac{G^2}{\pi} E^{*2} \qquad E^* \text{ is the c.m. energy}$$

$$\approx M_P^2 + 2 E_\nu M_P$$

as

$$E^* \to \infty \qquad E^* \sim 2 E_\nu M_P$$

$$\sigma_{tot} \sim 3 \times 10^{-38}\ E_\nu \text{ (GeV) cm}^2 ,$$

where G is the usual weak interaction coupling constant $\approx 10^{-5}/M_P^2$. This also rises linearly and is close (but not equal) to the observed total cross section up to 12 GeV. At least no gross form factor effects have damped the linear rise of the cross section by that energy.

Long ago it was pointed out that this linear rise cannot continue indefinitely without violating unitarity. The interaction is s-wave and the maximum possible cross section is $1/2\ \pi\lambda^2 \sim 1/2\ \pi/E^{*2}$. If we set $G^2 E^{*2}/\pi = 1/2\ \pi/E^{*2}$, we get $E^* \sim 450$ GeV, which corresponds to a laboratory energy of 10^5 GeV and a $\sigma_{tot} \sim 0.6 \times 10^{-33}$ cm^2.

But the cross section may turn over long before we reach this limit. Among the possible mechanisms which could accomplish this are:

1. Existence of the W meson, leading to the introduction of a form factor $\dfrac{1}{1 + q^2/M_W^2}$. The W meson was first proposed to save unitarity.

2. Damping effects of higher order weak interactions[2,3] of order $G\Lambda^2$ and $G\,\log(\Lambda^2/M_P^2)$--formally divergent when $\Lambda \to \infty$ (Λ is assumed cutoff). Various theoretical attempts to estimate Λ using the $K_S - K_L$ mass difference set $1/\Lambda \sim 3\text{-}15\,\mathrm{GeV}$. This could show up as a turning over of σ_{tot} in the high-energy limit.

If the W mass is M_W, then for $q^2 > M_W^2$, the cross section is reduced to $< 1/4$ of the point value.

If we assume

$$\frac{d\sigma}{dq^2} = \int \frac{d^2\sigma}{dM^{*2}\,dq^2}\,dM^{*2} \simeq \left[1\Big/\left(1 + \frac{q^2}{M_W^2}\right)\right]^2 \frac{G^2}{\pi},$$

we note that

$$\int_{\text{point},\, M_W \to \infty} \frac{d\sigma}{dq^2}\,dq^2 \simeq \frac{G^2}{\pi}\,E^{*2},$$

and

$$\int \frac{d\sigma}{dq^2}\,dq^2 = \sigma_{tot} = \left[E^{*2}\Big/\left(1 + \frac{E^{*2}}{M_W^2}\right)\right]\frac{G^2}{\pi}.$$

As

$$E_\gamma \to \infty,\ \sigma_{tot} \to \frac{G^2}{\pi}\,M_W^2.$$

3. A form factor (arising from strong interactions) setting in at very high q^2.

We can estimate the presently known lower bound for M_W by observing that the experimental σ_{tot} rises linearly up to 10 GeV. If the deviation is less than 20%, $M_W > 10$ GeV. This is already near the upper limit in mass of directly observable W's at the 200-GeV accelerator.

A 5% measurement of $\sigma_{tot}(E_\nu)$ for $E_\nu = 100$ GeV will set a limit $M_W > 70$ GeV if σ_{tot} remains linear. <u>This seems clearly higher than any other way of limiting</u> M_W. One would, of course, require actual observation of W's to prove their existence.

The other possibility, that the cross section turns over, is also interesting although less directly so. Presumably possibility (2) above, the damping effect, will cause deviations from the Lee-Yang-Pais formula which checks locality (see below). The third possibility can be checked by comparison with concurrent experiments on deep inelastic muon scattering. Since the weak and electromagnetic interactions are thought to proceed via the interactions of currents with each other, the spatial structure being probed by these currents is quite interesting. Especially interesting is this comparison between the electromagnetic form factor and the weak form factors. The vector part of the weak current should, by CVC, be exactly proportional to the vector part of the electromagnetic current.

By measuring $d\sigma/dq^2$ for deep inelastic muon scattering and assuming CVC, the axial form factor can be extracted from $d\sigma/dq^2$ for ν (or $\bar{\nu}$) inelastic scattering.

The difference $d\sigma(\nu)/dq^2 - d\sigma(\bar{\nu})/dq^2$ is proportional to the product of axial and vector form factors. Since this difference vanishes as $1/E_\nu$, it might prove hard in practice to separate vector and axial vector contributions without assuming CVC, but if a difference can be measured CVC can, in principle, be checked.

It would be interesting to see if the axial form factor differs from the vector and to compare the dependence on q^2 and $E_\nu - E_\mu \equiv \nu$ with the extension of the recent SLAC results.[4] Is the axial form factor also given by a function of q^2/ν? A dimensional "argument" would imply that it must be at high energies, if no other masses are present to provide scale factors.

Finally, the weak analog of the Rosenbluth formula can be checked. This is implied by the theory of current-current interactions and the locality of the lepton current.

The most general dependence[5] on E_ν (for fixed $E_\nu - E_\mu \equiv \nu$ and q^2) is

$$\frac{d^2\sigma}{dq^2 dE_\nu} = \frac{A(q^2,\nu)}{E_\nu^2} + \frac{B(q^2,\nu)}{E_\nu} + C(q^2,\nu) .$$

Thus, verifying this formula at the highest possible values of E_ν and q^2 sheds light on one of the most cherished hypotheses of weak interaction theory--namely, the point-like character of the lepton current and the vector-axial vector form of the interaction.

III. THE IDEA OF "TAGGING" NEUTRINOS

At present, the only way to determine $d\sigma/dq^2$ and hence $\sigma_{tot}(E_\nu)$ is to get E_ν a postieriori by adding up all visible energy in a bubble-chamber observation of the neutrino interactions. This has been done at CERN. As mentioned earlier, the method suffers from:

1. Large numbers of low energy interactions (since the ν spectrum rises more rapidly than $1/E$) all of which must be measured.

2. A need to correct for missing energy (π^0's, etc.). No procedure has yet been devised to check this directly.

3. Trouble in identifying the muon if there are several secondaries of the same sign. This happened in ~20% of the events with $E_\nu > 5$ GeV in the CERN BC.

We seek a method in which the ν energy can be known by some other means.

We observe that above ~50 GeV, almost all of the neutrinos come from K decay rather than π decay and that the kinematics of K decay differ considerably from those of pion decay, opening the possibility of forming a "monochromatic" π and K beam (known as a narrow-band system or NBS), say $\pm 5\% = \Delta p/p$ for p = 100 GeV/c, focusing this beam down a $\simeq$ 500 meter decay path, and collecting the muons from the K decay. The difference in Q-value between π and K decay allows one to isolate the low energy muons (high energy ν's) from the K decay without having to count the numerous μ's from π decay or to count the hadron beam itself. The decay kinematics for $K \to \mu\nu$ and $\pi \to \mu\nu$ decays are shown in Fig. 2. One measures the energy of the muon (or its angle) and determines E_ν by $E_\nu = E_K - E_\mu$. The easiest method seems to be measurement of the muon range by a range telescope surrounding the decay path. Measuring angles for the muon appears difficult because the angles range from ~4-11 mrad and the decays are spread over ~500 meters. However, a crude measurement verifying that the decay muon and the observed interaction vertex lie roughly in a plane containing the hadron beam would reduce background and allow an increase in the tagging rates possible. It will probably be necessary to veto particles emerging from the upstream part of the beam (before the decay path).*

Intensity of Tagged Neutrinos

Figure 3 shows the intensity of K^+ mesons as calculated by White and Awschalom.[6] $d^2N/d\Omega dp$ is given assuming 200 GeV/c protons incident on Be. The top curve is the predicted yield of K^+ at 2 mrad per steradian per GeV/c per interacting proton. The next two curves show the <u>integral</u> yields of neutrinos above 40 and 80 GeV as a function of the <u>parent</u> K momentum, assuming a 500-meter decay path. The curves show that a narrow-band system should be tuned to about 60 GeV/c to

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*Since the decay is a two-body one and the emerging neutrino angles range from 0-4 mrad (90-40 GeV), observation of the radial distance ($\leq 4 \times 10^{-3} \times 500$ m = 2 m) of the interaction vertex determines the longitudinal decay point within the 500-meter distance. For example, if the neutrino angle is $1 \pm 0.1 \times 10^{-3}$ from the decay kinematics, then the vertex must be 0-50 cm outside the beam. If the decay point can be determined from the range telescope to ± 50 meters, then on the average, we predict a radial distance of

$$\pm 10 \text{ cm} + (250 \pm 50 \text{ m}) \times (1 \pm 0.1 \times 10^{-3})$$
$$(\pm 10 \text{ cm is from the finite hadron beam size})$$
$$25 \text{ cm} \pm 2.5 \pm 5 \pm 10 \simeq 25 \text{ cm} \pm 12 \text{ cm}.$$

So some radial information is also available to us.

maximize 40 GeV/c neutrinos and 100 GeV/c to maximize neutrinos above 80 GeV/c.

In Fig. 4, we answer the question: How much, in terms of neutrino flux, do we lose by confining ourselves to a narrow band of hadron momentum (here assumed to be 100 ± 5 GeV/c)? The answer is a factor of ~12 for $P_\nu > 40$ GeV/c and ~5 for $P_\nu > 80$ GeV/c. This factor is the overall factor compared to the number arising in this decay length from all the hadrons produced in the target.

Table I gives expected intensities and counting rates for elastic and inelastic events. We note that the number of neutrinos/burst ≥ 40 GeV is just equal to, or slightly greater, than the limitation imposed by rate limitations in the counters (instantaneous rates in single counters are ~ $1/10 \times 1/8$ of the beam decay rates), but a reduction of a factor 2-6 in the maximum rate must be expected from counting rate limitations at the highest rates.

Table I. Intensities and Counting Rates for Neutrino Events.

	Neutrinos per Burst (NBS)	Elastic Events/Day	Total Events/Day
$E_\nu \geq 40$ GeV	5.6×10^8	30	2600
$E_\nu \geq 80$ GeV	1.9×10^8	11	1100
$E_{\bar{\nu}} \geq 40$ GeV	0.49×10^8	2.6	216
$E_{\bar{\nu}} \geq 80$ GeV	0.17×10^8	0.9	100

Assumptions in Making Table I Are:

Hadron beam:

10^{13} interacting protons on Be

$\Delta\Omega = 40$ μsr (~50% of 100 GeV/c K^+'s are collected)

$\Delta p/p = \pm 0.05$

$\theta_{prod.} = 2$ mrad; $K^-/K^+ = 0.088$

500-meter decay path

Detected Muons:

$\theta_\mu = 5$-10 mrad

$E_\mu \simeq 10$-60 GeV/c

Neutrinos:

θ_ν 0-4 mrad

E_ν 40-90 GeV/c

R < 2.5 meters (interaction detector radius)

Interaction Cross Sections:

Inelastic $0.6\,\bar{E}_\nu \times 10^{-38}$ cm^2 ($\bar{E}_\nu$ is the average ν energy)

Elastic 0.5×10^{-38} cm^2 ($\times$ 1/2, since only νp or $\bar{\nu}$n elastic scattering occurs)

Interaction Detector:

Probably a magnetized iron spectrometer with optical spark chambers and a vidicon readout. The interaction material could be the spectrometer itself. The assumed volume of material is 1.7 kG/cm^2 or 10^{27} nucleons/cm^2. This is equivalent to:

17 meters of H_2O

6.7 meters of Al

~2.2 meters of Fe

1 meter of U.

Hydrogen or Deuterium Target

If we confined ourselves to $E_\gamma > 80$ GeV we could use a 2-meter diameter cylinder of liquid hydrogen. If the length were 7.5 meters, then the rates would be 3% of the above or about 30/day above 80 GeV if induced by ν. This seems a reasonable rate, at least for σ_{tot} and allows us to look at both proton and neutron σ_{tot} (using deuterium) separately.

IV. ALTERNATIVES TO NEUTRINO TAGGING

A completely different approach might be to use the total absorption counter proposed by T. Kirk for W searches[7] with muon-produced W mesons. The neutrino energy might then be determined by adding up the light from the counter and the muon as measured separately with an iron spectrometer. The advantage of this counter is the simplicity, the disadvantage the bulk and cost which are considerable. A separate measurement of the ν spectrum would be necessary to determine a cross section, but the use of a wide band beam might boost the rates by factors ~5-10. On the other hand, a precise cross section vs E would be harder to do since one deals with the comparison of two exponentially falling curves and the correction might be hard to determine. This alternative very well might prove more attractive than the tagging and deserves careful consideration.

The most conservative approach would appear to be a duplication of the CERN technique using a heavy liquid bubble chamber. Whether this is indeed the conservative approach has not, to my knowledge, been considered critically.

V. FIRST THOUGHTS ABOUT A TAGGING SYSTEM

Priority should be given to tests of the feasibility of tagging hadron beams. The methods proposed, at least the "cheap" methods in which only the muon range is measured, are very sensitive to the presence of a muon halo around the beam or to off-angle hadrons exceeding 0.1% of the main beam. Almost any way of determining that the muons emerge from the vacuum would suffice to eliminate possible halo, but I am not able to think of something which doesn't involve measuring muon angle. This could only be done with Charpak chambers. The high rates and huge upstream distance from the interaction prohibits conventional spark-chamber operation. Only the simplest method of tagging is discussed here, and it is assumed that the beam design resembles that given by Berley and Hand in another 1969 summer studies report. This beam, if built, should be carefully designed to eliminate all effects of muon halo and off-angle hadrons. The latter are presumably caused by slit penetration or scattering, the former by hadron decays upstream of the last deflecting magnet. Since the muon halo is comparable in rate to the desired muons, a veto counter would probably work to eliminate most of the problem.

Either water (suggested by R. R. Wilson) or the existing dirt ($\rho \approx 1.8$) could be used to range out the K-decay muons. If we assume that at least three counters are required to define a muon and that the minimum energy muon we wish to detect is 10 GeV, the counters will have to be spaced every 5 GeV in terms of range. This is approximately 22 meters of water or 12.4 meters of dirt of density 1.8 gm/cm^3.

From 3-11 counters would then constitute an acceptable muon signal. Information as to which counters fired would be stored along with other data from the interaction detector. The condition of more than two counters firing could be used as an electronic trigger signal if desired.

Using dirt as the stopping medium, 40 counters would be distributed down the 500 meter decay path.

Additional counters might be placed behind iron absorber at the end of the decay path, but this would prove expensive. It would be better both to precede and to follow the 40 counters with somewhat larger veto counters. Using the veto counter following, the effective decay path in the worst case (50 GeV muon) is reduced by a factor 3/4. This has not been taken into account in the rate calculations.

We assume the individual counters surround the beam leaving a hole large enough to allow a vacuum pipe to pass through--about 10 inches should be enough. Each counter is further divided into 8 trapezoidal sections which fit together to form an octagonal cross section.

How wide is the transverse direction of the counters? From range requirements alone, combined with the kinematics of K decay we see that the transverse dimension is just $P_{TR}/(d\bar{E}/dX)$. Since the maximum transverse momentum is 0.235 GeV/c, the maximum "transverse range" is about 100 gms/cm^2, i.e. 1 meter of H_2O or 56 cm of dirt. The minimum penetration depth for the muons of interest here is roughly 1/2 of the above. Multiple scattering causes fluctuations in this. Assuming the radiation length in water to be 37 cm, and in dirt (use X_0 for Al) to be 13 cm, we use the ancient formula in Rossi's book for the projected multiple scattering distribution

$$\langle y^2 \rangle = \frac{\theta_s^2 x^2}{6} \qquad \theta_s = \frac{0.021}{p_{BeV}} t^{1/2}$$

(x is distance in meters, t thickness in radiation lengths). For p we make the crude approximation of half the initial momentum. The result is shown in Fig. 5.

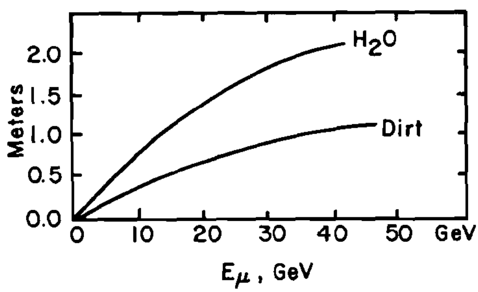

Fig. 5.

Water absorber implies counter transverse dimension ≈ 1.0 m + 1.8 m ≈ 3 m outer radius. A dirt absorber gives 0.6 + 1.3 ≈ 2 m outer radius. Thus, we save a factor 2 in counter volume using dirt absorber.

A two-inch thickness of liquid scintillator should be ample, yielding about 5×10^4 visible photons. Without the use of adiabatic light pipes a single 2-inch photomultiplier (15% photocathode efficiency) will give about 3 e/ℓ - e photoelectrons. (e is the effective reflectivity of the counter internal surface, assuming perfect isotropy and no attenuation in the liquid scintillator, which is not only cheaper than plastic but has a much longer attenuation length.) A conservative estimate gives e = 0.8 and 12 photoelectrons for a minimum ionizing particle. Two phototubes are used for redundancy. Each counter section has about 70ℓ volume and if the cost of liquid scintillator is \$5/ℓ (an upper limit), the whole unit can be built for under \$850. Here we have allowed \$400 for phototubes and bases (2 tubes), \$350 for the scintillator and \$100 for the plastic container which could be injection molded in quantity. Some effort could be spent to reduce the cost further since there are 8 sections/counter and 40 counters. $320 \times \$0.85\,K = \$270\,K$. This is just for the counters alone and does not include excavation of the decay tunnel, cabling down the beam line, muon shielding at the end and experimental detection apparatus plus other as yet unforeseen expenditures. It is clear that this would not be a cheap effort and the tagging must have a very high probability of working. Probably the total cost of an experiment to do inelastic neutrino scattering is in the neighborhood of \$1M.

Counting Rates, Electronics

At the maximum possible rate of 6×10^8 K-decay neutrinos per burst, each event illuminates on the average 7 counters and we have a counting rate

$$\frac{6 \times 10^8 \times 7}{320} = 13 \text{ MHz}.$$

This instantaneous rate is rather high and will probably have to be reduced by a factor of 5 or 6 to avoid swamping the counters. This, of course, reduces the maximum data rate to ~350 events/day for the conditions of Table I, still a good rate.

Figure 6 shows schematically what the electronics might be. To eliminate accidentals we need a fast coincidence ($\leq$ 10 nsec), but we cannot afford to run 320 cables. Instead, the output of a discriminator which receives the summed photomultiplier signals is fed into 2 cables, a "fast" ($V = 0.98c$) and a "slow" ($V = 0.92c$) cable. These cables run the entire length of the beam and are duplicated 8 times for a total of 16 full length cables. Short (<5 nsec) pulses of standard height are fed from each discriminator onto the "fast" cable with appropriately varying lengths (increasing by 2.6 nsec/section) so that the signals from a single event overlap each other in time. Nearly coincident signals (coincident with the interaction signal) pass through a fast gate 20 nsec and are analyzed by an ADC (for the number of counters firing) and a time-height converter which measures the accidental/real ratio while data is taken.

Another fast signal from the observed interaction is stored in a 10 nsec cable (or a 100 mHz triggered oscillator could be used) and then placed in coincidence with the "slow" cable signal. A shift register (40 bits long) indicates which counters fired during that event using the output of the coincidence circuit to drive flip-flops in the shift register.

The accidental rate (at 10^8/burst), if a 10 nsec coincidence (FWHM) can be maintained, is about 1/8 of the signal and a background subtraction must be performed.

Good statistics on the accidentals can be obtained by looking at counters of the wrong azimuth. Of course, higher rates are possible if the coincidence can be improved or a larger subtraction tolerated. Additional bits may register in the shift register, but the correct train of bits is recognized by having the length given by the ADC.

VI. CONCLUSION

Neutrino tagging looks promising, with a yield on the order of several hundred inelastic neutrino events/day. With the reduced beam intensity (1/6 maximum) parasitic operation could be envisaged. A more thorough design and better cost estimate should await a detailed comparison of the same experiment done either with the 25-ft bubble chamber, or with the total absorption detector proposed by T. Kirk. The physics appears to justify a high priority for at least one of these approaches.

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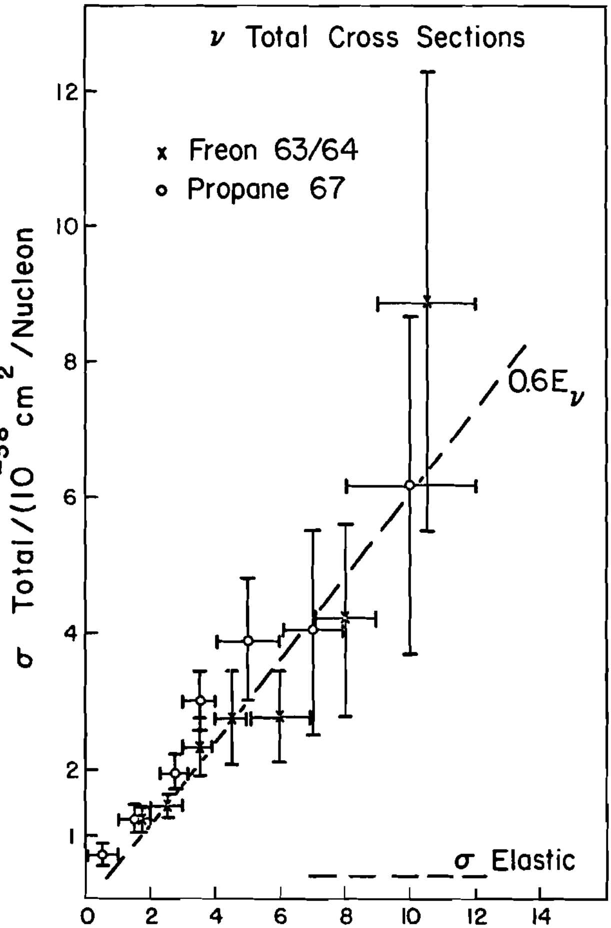

Fig. 1. CERN Heavy Liquid Bubble Chamber results for σ_{tot} vs E_ν. Taken from Ref. 1.

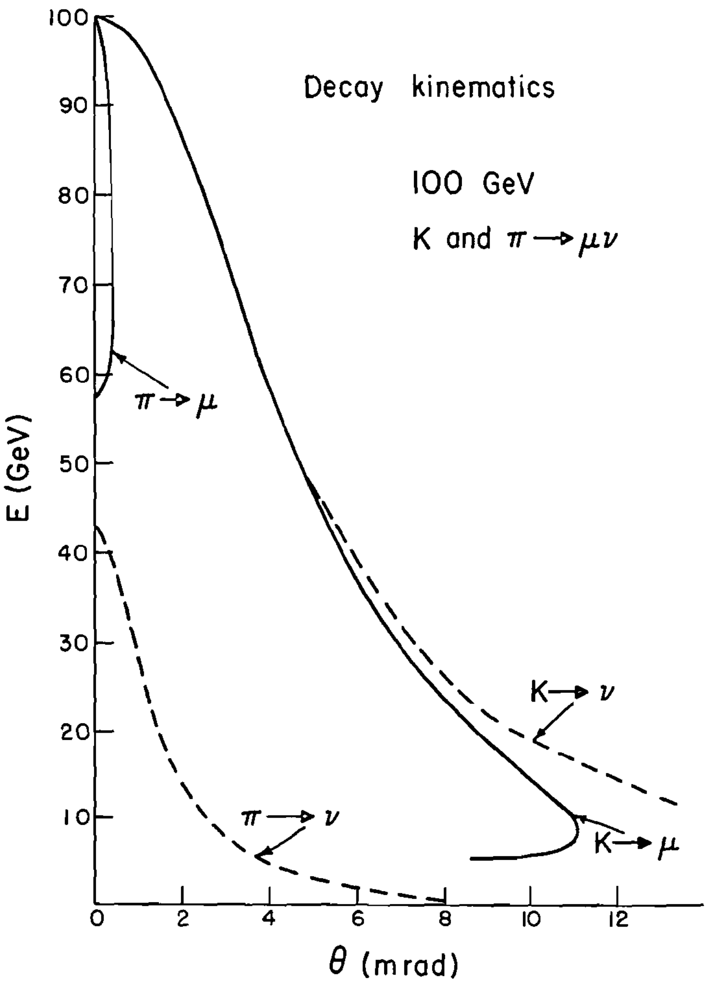

Fig. 2. Decay kinematics for $K \rightarrow \mu\nu$ and $\pi \rightarrow \mu\nu$ decay.

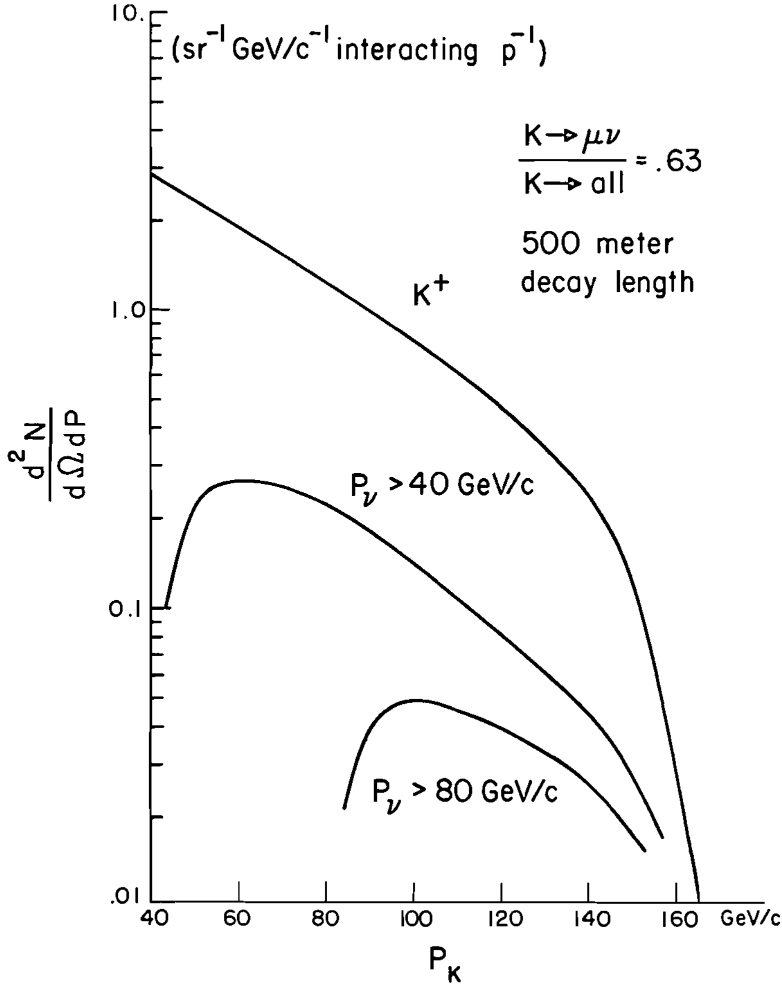

Fig. 3. K^+ yields for 200 GeV/c p on Be taken from Ref. 6. Also shown is the differential yield of neutrinos > 40 GeV/c and neutrinos greater than 80 GeV/c for a given K momentum.

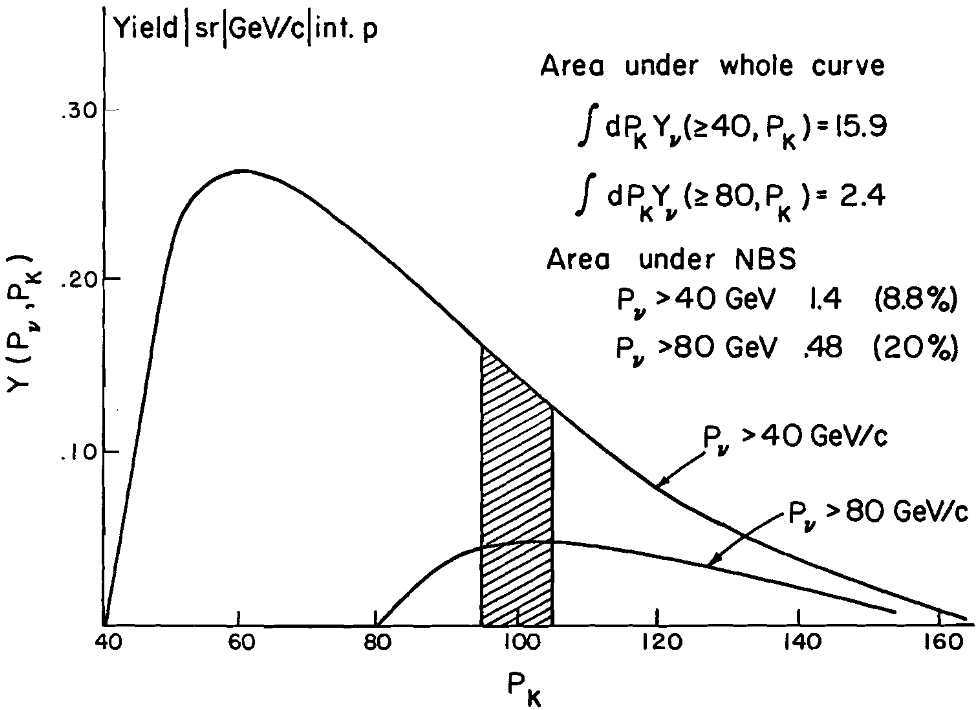

Fig. 4. Neutrino flux available compared to the amount selected by the NBS ($\Delta p/p = \pm 5\%$).

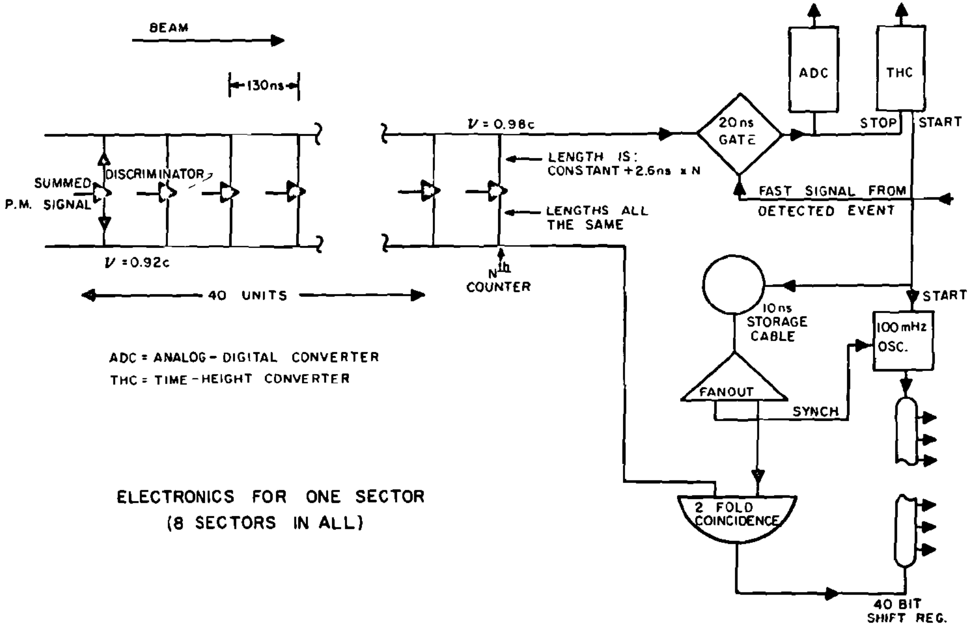

Fig. 6. Possible block diagram of tagging electronics.