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MEMORANDUM

Copy to/Copie à:

To/A: The SPSC Members

From/De: C. Fisher, R.L. Sekulin, W. Venus and H Wachsmuth

Subject/: Concerne Neutrino experiments using the RCBC?

There are still many questions to be answered by neutrino experiments (see the various talks at the recent fixed target workshop). In particular the continued operation of the wide band neutrino beam with new and upgraded detectors at CERN throughout the 1980's seems clearly justified by the physics and physicists' interest.

In this note we focus on two aspects of the program: The study of flavour changing interactions and the study of charm and possibly beauty particle properties.

Flavour changing interactions can only be studied with neutrinos. However, present neutrino detectors have only very limited access to this field of neutrino physics because of the lack of secondary particle identification. Only restricted and possibly very biassed subsamples of $|\Delta C| = 1$ interactions have been observed(*), and $|\Delta S| = 1$ interactions are completely inaccessible with detectors currently in operation at the SPS because without $\pi^\pm/K^\pm$ separation one is never sure that the final state contains only one strange particle.

An important aim of such studies would be the better determination of the Kobayashi-Maskawa mixing matrix elements U_{SC}, etc. For this the levels of the strange and charmed sea must be measured. With efficient particle identification this could be done by studying neutral-current production of large-rapidity-gap strange particle pairs. Similarly charm pairs could be directly observed if the resolution of the detector is sufficiently high.

(*) Opposite-sign dilepton events ($\mu^\pm\mu^\mp$ and $\mu^\pm e^\mp$) observed in calorimeter-type experiments and bubble chambers have the gross features expected of fast charmed $D^\pm$-meson production and semileptonic decay. They are therefore commonly, and probably correctly, ascribed to this source despite the fact that the origin of the same-sign dilepton events ($\mu^\pm\mu^\pm$ and $\mu^\pm e^\pm$) observed is totally obscure. Bubble chambers and emulsions have observed handfuls of other events in addition.

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The value of particle identification, both charm and strange, for more general fragmentation function studies is obvious.

The advantage of neutrinos as a source of charmed particles for general studies of charm is clearly that the signal to background is 8% compared with $\sim$ 1% in photoproduction and 0.1% in hadroproduction. This reflects strongly in the background and triggering problems and the difficulties of data analysis.

Such studies require a high spatial resolution (holographic) bubble chamber in combination with external particle identification and electromagnetic and hadronic calorimeters [1]. A practical approach at the present time requires the use of existing material as much as possible and as soon as possible.

We therefore propose the installation, as soon as possible, of RCBC in the West hall in front of BEBC in the present wide band neutrino beam line. The existing and operational chamber, the RCBC, can be effectively used for such ν-studies. The important questions are clearly rate and resolution.

(a) Rate

If the chamber is operated with a neon filling using the existing body, etc. 10^{19} protons on target would yield $\gtrsim$ 50 K cc ν events producing $\sim$ 4 K charmed particles. This rate is about one half of that in BEBC filled with hydrogen (even the standard 75 wide % neon-hydrogen filling would yield $\sim$ 35 K cc ν events with $\sim$ 3 K charm).

(b) Resolution

The detection of the charm vertices depends critically on the resolution. Tests performed at the Rutherford Laboratory reported at the EHS Strasbourg Workshop [2], have shown that using the RCBC geometry it is possible to achieve a resolution of $\sim$ 20 μm in space using holography. It is necessary to attach a mirror to the existing piston however this would not be a problem on a chamber of this size. Resolution in the region 20-30 μm is sufficient to detect decays corresponding to $\tau \gtrsim 2 \cdot 10^{-13}$ s with good efficiency (HOLEBC experience). If all events are measured, which because of the high signal to noise would be easy for a neutrino experiment, even shorter lifetimes can be probed.

A further increase in event rate could be achieved by enlarging the chamber body. A higher priority however is clearly to provide high quality high resolution holographic optics channels (substantially better quality and resolution should be achievable than in BEBC and hence much better charm detection efficiency particularly at short lifetimes (D^0, F, Λ_c, τ)).

In addition a suitable large acceptance external charged particle identifier (such as ISIS or RICH) and photon and hadron calorimetry must be provided.

Clearly further study is required to optimise a feasible layout and to evaluate its true potential. However, we believe it is clear that a valuable neutrino program inaccessible to and complementary to those of other detectors could be carried out using the RCBC in this way. Operation would be at the same time and in the same beam line as existing detectors and at minimal additional cost depending on the availability and utilisation of existing equipment.

REFERENCES

[1] W. Venus and H. Wachsmuth, CERN TC-L/Int. 75-3, copy attached.

[2] A. Miranda, EHS Strasbourg Workshop, CERN Yellow Report, CERN 82-01 (1982).

TC-L/Int. 75-3
26.6.1975

SOME THOUGHTS ON THE POSSIBILITY OF NEUTRINO EXPERIMENTS WITH COMPLETE FINAL STATE RECONSTRUCTION USING A HYBRID TECHNIQUE

("ν Ω")

W. Venus*, H. Wachsmuth

SUMMARY

For neutrino interaction studies which depend on complete final state reconstruction, a detector is needed which allows observation of vertex details <u>and</u> final state particle identification and measurement. This applies in particular to $\Delta S = 1$ interactions, in which single produced strange particles have to be distinguished from a 3 to 10 times higher background of associated strange particle production, and to q^2-ν plots for neutral current interactions. Principles of a detector set-up combining bubble chamber and counter techniques are discussed.

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I) INTRODUCTORY REMARKS

I.1 Where do we need final state reconstruction ?

One large area of neutrino physics at present discernable which depends on observation of vertex details (down to a few millimeters) and final state particle identification and measurement is the study of $|\Delta S| = 1$ processes. If at all possible it should certainly be studied at high q^2 with neutrino beams as well as at low q^2 in kaon and hyperon decay, particularly since predicted new effects such as "charm" may well be more clearly manifest in $|\Delta S| = 1$ than in $\Delta S = 0$ channels (as for example in the GIM-model). The main experimental problem is the separation of $|\Delta S| = 1$ processes (< 5 % of the total event rate) from $\Delta S = 0$ processes with associated production (perhaps 15-20 % of the total event rate at high energy, see appendix A). This can only be solved by :

(1) identifying charged particles, particularly kaons,

(2) detecting γ rays, neutrons and K^o_L, and

(3) observing hyperon and K^o_S decays (mostly close to the vertex).

Another large area of neutrino physics with similar experimental requirements is the study of neutral current processes involving undetectable outgoing neutrinos. The measurement of q^2 over a wide range depends on proper mass assignments to the particles produced, even in narrow band beam experiments (see appendix B).

I.2 Present limits of counter and bubble chamber experiments

The basic experimental requirements for detailed studies of $|\Delta S| = 1$ and neutral current processes can be summarized as follows :

1. H_2 (and D_2) targets to avoid secondary nuclear effects.
2. Sufficient visibility and measurability near the vertex to identify essentially all $\Sigma^\pm$, Λ, K^o_S.
3. Essentially complete $K^\pm$ and K^o_L detection and identification ($\pi^\pm K^\pm p$ separation).

4. Muon identification

5. High total event rates because $\sigma(\Delta S = \pm 1)/\sigma(\Delta S = 0)$ is small.

These are difficult to satisfy simultaneously. For example BEBC satisfies (4) rather well as a result of partial hybridisation (provision of the external muon identifier) but cannot satisfy (3). Certain simple $|\Delta S| = 1$ channels can of course be separated even in bare BEBC by 3-c kinematic fitting such as $\bar{\nu}p \rightarrow \mu^+\Lambda$, $\mu^+ \Sigma^+ \pi^-$ and possibly $\bar{\nu}n \rightarrow \mu^+ \Sigma^-$, $\mu^+ \Lambda \pi^-$, $\mu^+ \Sigma^+ \pi^- \pi^-$, using events with an additional detected K^o_S to evaluate the associated production background. However, such channels will amount to only a small fraction of the total $|\Delta S| = 1$ cross section at high energy. Also they will occupy a restricted region of the $q^2 - \nu$ plane where the probability of observing new effects is relatively small.

Electronic techniques offer the advantages of timing (avoiding wrong event correlations), calorimetry (energy measurement in case of charged current interactions), identification of fast charged particles using Čerenkov relativistic rise detectors, large target mass (search for rare processes not depending on vertex details like 2 muon production), special design for processes with relatively simple signature (like ν-e scattering). However, no electronic technique has yet been developed that can satisfy requirement (2).

I.3 The use of a track-sensitive target (TST) inside a heavy liquid bubble chamber

The use of heavy liquids surrounding a suitable track sensitive target (TST) filled with hydrogen or deuterium - as already proposed for BEBC (1) - would provide a partial solution. It has the advantages of hydrogen-chamber-like measurability for charged particles and neutral strange particle decays and simple hydrogen or deuterium nuclei largely free of complication due to Fermi motion and secondary interactions within the nuclei. It would also largely solve the problem of detecting neutral hadrons provided event rates in and around the chamber are limited sufficiently to allow detected neutrals to be associated correctly with their origins. Some information on fast $\pi^{\pm}/K^{\pm}/p$ identification will be obtainable by exploiting the relativistic rise in the bubble density of fast particles in Neon-Hydrogen mixtures [2). A further bonus would be the ready identifiability of electrons in the heavy liquid.

However, direct measurement of the energies of detected neutrons and K_L^0 would presumably remain about as problematic as in Gargamelle at present. In charged current events these energies can in principle be determined rather well from a kinematic fit (2C in a wide band beam if one neutron or K_L^0 considered to be of unknown energy is detected and all other neutrals are both detected and measured). But this cannot be done in neutral current events. Similarly charged kaons will seldom be directly identified and kaon identification will generally also depend on a kinematic fit (3C if all neutrals detected and measured). This latter fit is expected to work reasonably efficiently for charged current events in hydrogen for fairly low neutrino energies (up to perhaps about 40 GeV). But it will not work for neutral current events, nor for higher energies, nor in deuterium.

Thus while the TST technique represents a considerable step forward and will permit an initial attack on these problems it is not the final answer. In the longer term an alternative solution must be found.

I.4 Separate function hybrid detector system

Since no single detector technique fulfils all the experimental requirements listed above, we consider a separate function hybrid detector system designed according to the following scheme (fig. 1).

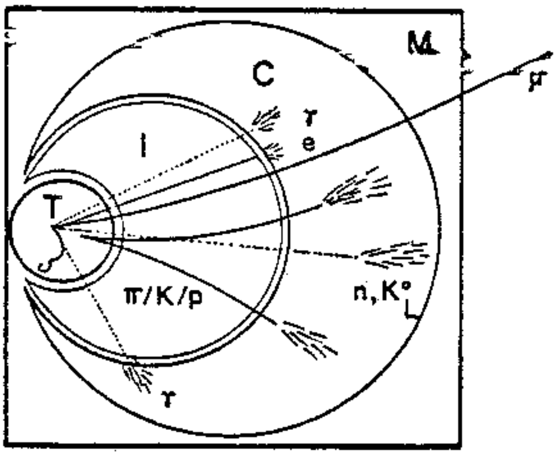


Fig. 1

T : $D_2(H_2)$ Bubble chamber
for event production
vertex observation
detection of Λ, K^o_S, $\Sigma^\pm$, and spectator nucleon in D_2
measurement of low momentum large angle secondaries.

I : Charged hadron identifier
for $\pi^\pm/K^\pm/p$ separation

C : Total absorption calorimeter
for detecting and measuring gammas, neutrons and K^o_L
identifying and measuring electrons
identifying muons

M : Magnetic field
for identifying and measuring K^o_S, Λ , low momentum electrons and hadrons in T
measuring hadron momenta in T and I
measuring muon momentum in T, I and C.

II) A POSSIBLE HYBRID DETECTOR

II.1 Outline of design

The general idea guiding the design was to use only known or almost known techniques. Dimensions given followed only from general concepts ; details obviously depend on the results of an overall optimization study.

The neutrino target (fiducial volume) must contain liquid H_2 or D_2 and must be track sensitive in some way so as to detect hyperons and K^o_S (and a magnetic field must be provided for their measurement). The two alternatives appear to be to use standard bubble chamber techniques or to use sense wires (3). The electronic technique would be preferable, matching better the rest of the system and allowing thinner target walls, but would require substantial research and development and would probably be unable to give the required spatial resolution.

Outside the target one must detect the remaining neutrals and identify the charged particles, using electronic techniques. Its downstream wall must therefore be a fairly small fraction of a conversion length/interaction length thick in order to allow gammas and fast hadrons to get out into the electronic apparatus. For the same reason one gains only very slowly in useful event rate by making the target longer in the beam direction than a fraction 1/n of a hadron interaction length, where n (~ 4 ?) is the mean number of fast hadrons in events of interest. And the coat of the detector will increase fairly rapidly with the size of the target. Thus while a more detailed optimisation study is clearly needed it would seem that the target should probably not exceed a sphere of order 1 metre radius (4.2 m^3, 1/4 ton H_2, 1/2 ton D_2, event rate ~ 0.5 events/ton/10^{13} protons per pulse in a 400 GeV/c wide-band beam). The event rate in this target may seem very small. But one should bear in mind that even now only ~ 10^4 events have been measured in total in all neutrino experiments up to the present date. These statistics could be equalled in ~ 10 days continuous running with this target. And the events in this target will be completely reconstructed.

The neutral hadrons must be detected via their interaction in a total absorption calorimeter and the charged hadrons must be identified before they interact. So the target must be followed by a large-aperture charged-particle identifier. This could be a Čerenkov radiation detector system or an ionisation detector such as is planned as the downstream particle identifier for BEBC (5) or for the rapid cycling bubble chamber, proposed for the SPS North area (4).

The charged-particle identifier would then be followed by a gamma and hadron calorimeter of similar aperture. This would be ~ 10-15 interaction length thick to totally absorb all hadrons (especially neutrons and K_L^o) and identify any transmitted charged particles as a muon. The first 10-15 radiation lengths would be finer-grained and contain high-Z material (e.g. lead plates) to convert and identify gammas and also to identify and measure electrons. The target-to-calorimeter distance should be large enough, and the calorimeter density and spatial resolution high enough, that the cascade due to an individual neutron or K_L^o can nearly always be clearly distinguished, at least at its point of initiation, and also can generally be measured separately (to an expected precision ~ $.3/\sqrt{E}$, i.e. ± 20 % at 2 GeV, ± 10 % at 10 GeV and ± 4 % at 50 GeV).

In addition one needs magnetic fields in order to determine the charges of the charged particles, assist in identifying the strange particle decays, measure the momenta of the slow hadrons not reaching the calorimeter or poorly measured in it, and measure the muon momentum. We assume that momentum precisions of ± 5 % can be regarded as excellent and ± 10 % as acceptable. The most difficult task is to measure the muon (typically carrying the highest momentum).

The construction of the magnet is also important. The basic requirements are that it should allow excellent egress for gammas and hadrons and not act as a source of background neutrons in the target.

A possible schematic layout is shown in fig. 2 .

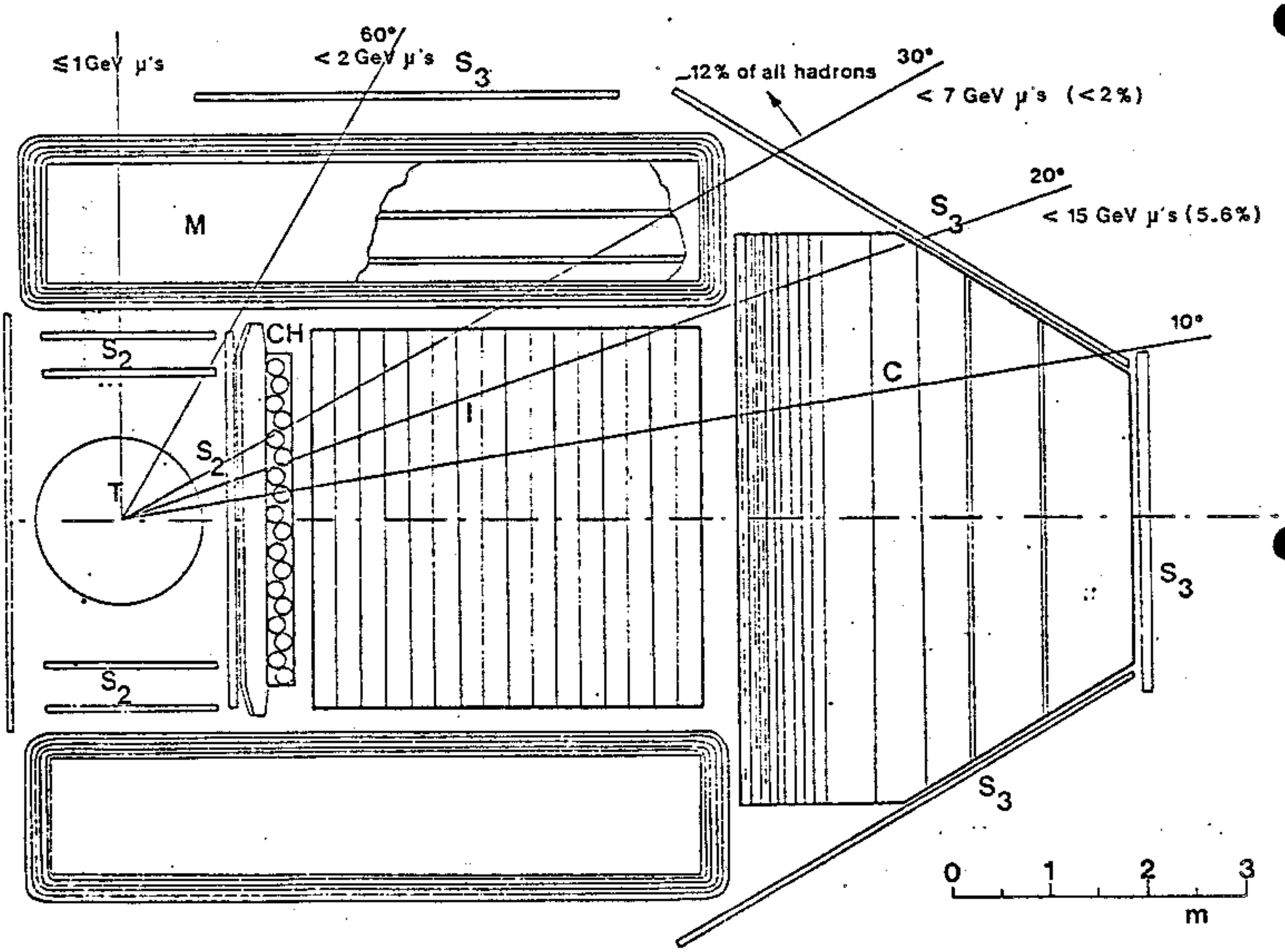


Fig. 2 Schematic layout of a possible hybrid neutrino detector following the scheme of Fig. 1 ("ν Ω"). All dimensions are arbitrary.

Having outlined the possible structure of the apparatus as a whole, let us now briefly reconsider the various elements in turn.

II.2 Target

As indicated above, the downstream wall should be as thin as possible in order to minimize the probability of gamma conversion (and also of hadron interaction). Table I compares three wall materials, assuming walls of 1 m radius of curvature and a hydrogen filling, using the design data of the rapid cycling bubble chamber proposal $^{(4)}$ as a reference. If the radius of curvature of the exit wall is increased its thickness will have to be increased in about the same proportion.

Material	λ_{ABS} (cm)	λ'_{CONV} (cm)	Necessary wall thickness (mm) of BC + vac. tank scaled from SPS RCVC proposal $^{(4)}$	P^{h}_{INT}	P^{γ}_{conv}	Escape probability	
						$1\ \pi^{0}$	$2\ \pi^{0}$
Steel	17.1	2.4	2 x 7.5 mm	8 %	54%	22%	5%
AL	38.8	11.7	2 x 7 (SPHER)	3.5%	11%	71%	62%
			2 x 14 (CYL)	7 %	21%	62%	38%
TI	28	4.8	2 x 1.5 (SPHER)	1 %	6%	88%	78%
			2 x 3 (CYL)	1.8%	12%	78%	61%

The useful event rate in a target of length L in the beam direction is approximately proportional to $\int_0^L e^{-\frac{n\ell}{\lambda}} d\ell \ \alpha \ 1 - e^{-\frac{n\ell}{\lambda}}$ where n is the mean number of particles per event that one needs to measure outside the target and λ their attenuation length. Thus for $L = \lambda/n$ one has already 65 % of the maximum possible useful event rate and gains only slowly by increasing L further. To take losses in the walls into account, we observe from Table I that for an event in the centre of a spherical target, the probability of loosing a gamma ray by conversion in spherical aluminium walls (perhaps the best choice) is about equal to that of loosing a fast π or K meson by interaction in the walls or by inelastic interaction ($\lambda \sim 12$ m) in hydrogen. Thus λ is effectively ~ 9 m for both fast mesons and gamma rays.

Hence a spherical chamber body of ~ 1 m radius seems to be about optimum. This would also be reasonably commensurate with the size of the neutrino beam. Obviously the spherical shape has to be distorted on top for three cameras (*) and on bottom for the expansion system such that the fiducial volume remains ~ 4.2 m^3. The alternative of a cylindrical construction may be preferable for technical reasons although it requires wall thicknesses twice as large.

Apart from satisfying these basic requirements the overriding consideration in a detailed design must be simplicity and cheapness of construction. It should probably be conceived as a sealed-down thin-walled version of the NAL 15' chamber.

A reasonable guess of the measurement precision obtainable in such a chamber might be $\varepsilon \sim 200\ \mu$ in space (cf. $\varepsilon \sim 300\ \mu$ in the larger ANL 12' chamber).

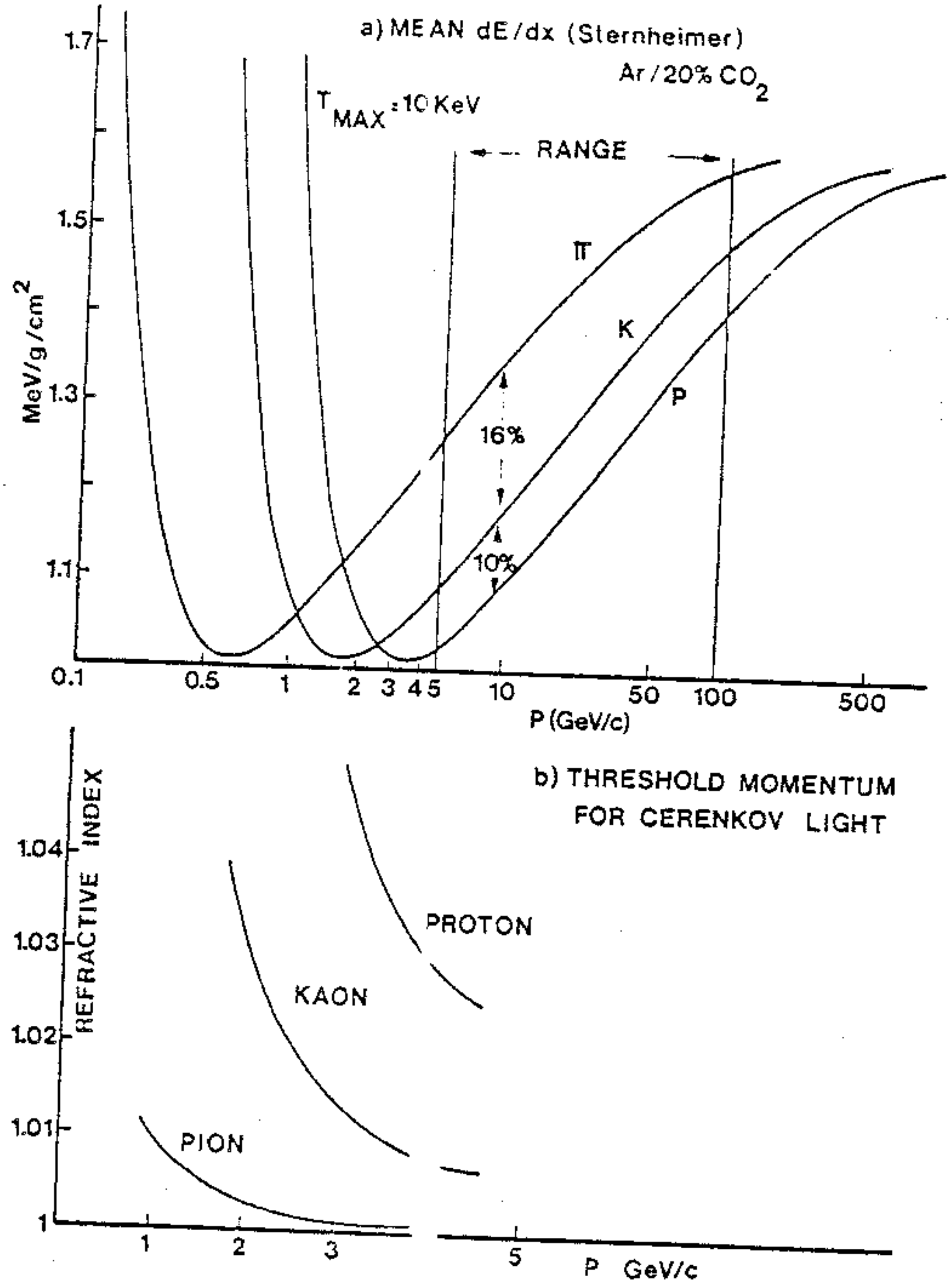
(*) A fourth camera could be mounted with its optical axis perpendicular to the magnetic field lines in order to increase the probability of identifying low momentum large angle secondaries by bubble density measurements.

II.3 Charged Hadron Identification

The most stringent condition is charged kaon identification. Pions, kaons and protons can be distinguished in principle by their different Cerenkov radiation or relativistic rise in energy loss. According to preliminary experimental experience (4-6), a multi-layer relativistic rise detector of the order of 5 m total length should provide sufficient resolution (~ 5 % FWHM) to achieve π/K/p separation with only 10 to 20 % overlap at 50 GeV/c and better below. The problem arising when used in a neutrino detector is the large surface to be covered for the required acceptance of most of the final state particles. Depending on the optimization of the whole detector set-up, a total volume of 50 to 100 m^3 might be necessary. Drift chambers within the detector are necessary to follow individual particles. γ-conversion inside the dE/dx counter can be kept as low as 2 to 3 % (6).

A large fraction of secondary hadrons is expected to have momenta between 1 and 4 GeV/c (Fig. D 2, appendix D), where momentum and ionisation measurement alone often cannot distinguish between π/K/p (see Fig. 3 a). In this momentum region π//K/p distinction could be achieved by adding a system of Cerenkov detectors (Honeycomb arrangement or 2-plane hodoscope for spatial separation) with a threshold such that the ionisation signal ambiguity is resolved (using a refractive index ~ 1.035, see Fig. 3 b).

An alternative could be a system of Čerenkov detectors only. For instance, a sequence of liquid helium (~ .5 m), n-penthane (~ 1 m), and CO_2 (~ 1.8 m) would distinguish kaons from protons between 2.5 and 40 GeV/c ; the momentum range could be extended to 60 GeV/c by an additional 3 m of H_2 . A complex Monte-Carlo study will be necessary to investigate the technical feasibility of arranging mirrors such that sufficient spatial resolution is achieved.


a) MEAN dE/dx (Sternheimer)
Ar / 20% CO_2
T_{MAX} = 10 KeV
RANGE
MeV/g/cm^2
1.7
1.5
1.3
1.1
π
K
P
16%
10%
0.1
0.5
1
2
3
4 5
10
50
100
500
P (GeV/c)
b) THRESHOLD MOMENTUM FOR CERENKOV LIGHT
REFRACTIVE INDEX
1.04
1.03
1.02
1.01
1
PROTON
KAON
PION
1
2
3
5
P GeV/c

Fi 3

II.4 Calorimeter (for single electromagnetic and hadronic shower absorption and muon identification)

The calorimeter could for example be either a liquid Argon detector with iron plates (8) or an iron-plate scintillator sandwich set-up (9), with wire/drift chambers in between for individual track following. At the present time it is not yet clearly established which solution allows more precise energy measurements. The iron plate scintillator set-up could be magnetised and serve as a momentum spectrometer.

The first 10 to 15 radiation lengths of this single particle calorimeter should be "fine-grained" in order to serve as a total absorption shower detector for reconstruction of gammas and for electron energy measurement.

This part should be followed by a 10 to 15 interaction lengths long system of calorimeter cells with the purpose of (a) measuring neutron/K_L^o directions and energies, (b) absorbing the total hadron cascade, and (c) thus identifying a possible muon by missing hadronic interactions. It should be pointed out that the muon identification efficiency in this device is larger than in a 1 - plane - EMI as foreseen for BEBC due to the track sampling inside the calorimeter. A neutron/K_L^o cascade will not always be completely separated from all other hadron cascades. However, knowing the number of charged hadrons hitting a calorimeter cell (from the track-following wire/drift chamber system) and their momenta (from the measurement in the magnetic field), the neutron/K_L^o energy could be deduced also in this case although with larger errors.

K_L^o-neutron distinction could be achieved in principle by applying the baryon number conservation law.

Background neutrons and K_L^o interacting in the chamber and thus simulating neutral current (muonless) events, would after be identifiable as such by their time coincidence with some tracks not originating from the chamber.

II.5 Magnet

The function of the magnetic field was briefly discussed in Fig. 1 and in the outline above : momentum measurement and identification of K_S^o and Λ decays and low energy electrons and hadrons inside the bubble chamber, and momentum measurement of all fast charged hadrons and leptons inside and outside the bubble chamber. If one assumes that precise kinematic fillting is unnecessary, because the aim of the layout design is to detect and directly identify all secondary particles, then the total bending power $\int Bdl$ is determined by the precision required to measure the highest momentum muons (precision in q^2). In order to achieve $\frac{\Delta p}{p}$ of the order of 10 % for 100 GeV muons inside the bubble chamber (~ 1 m track length), a magnetic field of 20 to 30 kG is required. This is not only unnecessary for the rest of the event analysis (most of the secondary hadrons have momenta below 5 GeV/c) but also uneconomic, since the resulting fan-out of the charged particles would require wider identification devices for hadrons and leptons. A preliminary conclusion is that a 5 kG field covering the target (bubble chamber) and the charged hadron identifier, i.e a volume of ~ 7 x 5 x 5 m^3, would meet all requirements. It would measure the momentum of a 100 GeV muon to ~ ± 5 % with 100 % acceptance assuming a wire/drift chamber system with .3 mm resolution.

The cheapest solution for such a magnet seems to be a so-called O-magnet using ordinary steel (magnetisation up to 10 kG). Details of the design (like gaps for light guides, possible scintillators inside the yokes to assist large angle muon identification, etc) again are determined by the overall layout optimisation.

If it turns out that the particle identification by ionisation sampling does not work satisfactorily inside magnetic fields, an alternative solution could be envisaged with a stronger magnet (10 - 15 kG) at the bubble chamber and a magnetised iron plate scintillator sandwich set-up as a calorimeter, implying less acceptance for measured muons.

II.6 Data Acquisition System

a) Much of the event analysis could be performed electronically. A data acquisition system recording all signals from the wire chamber, $\frac{dE}{dX}$ counters, calorimeter cells, etc. would

- collect tracks belonging to the same event and reject others (from events outside the chamber, cosmic, ...),
- reconstruct γ's, π^0, Λ's, n's, K_L^o
- calculate all E_h, $E_{h,tot}$, E_μ, raw q^2, ν, ...
- classify the charged hadrons
- classify event type

b) The rest of the analysis would be done from measurements on the bubble chamber film : initial particle directions, low energy particles not reaching the electronic detector, particles having interacted or decayed inside the chamber, number and direction of V's (practically all strange particles below 20 GeV decay inside the target), electron identification.

III) EVENT RATES

The rate estimates are based on the predictions for a 400 GeV layout for the CERN West Area (see appendix C) : 0.4 events (total) per ton and 10^{13} protons in a realistically focused wide-band neutrino beam (0.06 in $\bar{\nu}$ beam). Assuming 10^{19} protons for ν and 2.10^{19} protons for $\bar{\nu}$ experiments (~ 100 and 200 days of running), respectively and 1/2 ton (fiducial) deuterium (1.5×10^{29} protons, neutrons or electrons) and the physics assumptions of appendix D, one expects the following event rates (table 2) :

	ν	$\bar{\nu}$
total charged current interactions on n	270000	40000
" " " " " p	130000	80000
elastic charged current interactions	6000	6000
neutral current interactions	80000	50000
$\lvert\Delta S\rvert = 1$ total	4000	6000
elastic		300
associated production of strange particles ($\Delta S = 0$)	80000	24000
$\nu_\mu e \rightarrow \nu_\mu e$	30-320	27-470
$\nu_e N \rightarrow e H$	2000	600

The number of useful events will depend on the problem to be studied. For total cross-section measurements above 3 GeV (μ identification close to 100 %) essentially all events can be used; $\lvert\Delta S\rvert = 1$ studies depend on secondary hadron identification and hence on the probability for all fast hadrons to reach the identification device before interaction (see Fig. 3). Distributions of $x = q^2/2 M\nu$ in neutral current interactions depend on precise measurement of $\Sigma E_h - \Sigma p_{xh}$ (appendix D) and hence have to be measured in hydrogen (no Fermi momentum); in deuterium the useful number of neutral current events for x - distributions will be limited by the visibility of the spectator nucleon.

IV) COSTS

Obviously figures for costs can only be obtained after a careful optimisation study of the entire layout. However, as a guide line, a crude estimate is made based on corresponding estimates in existing SPS experiment proposals :

Bubble Chamber

	SPS-RCBC prop. (4)	scaled to bubble chamber described in section II.2	
Body	.3	1.0	
Expansion	.7	.7	
Optics	.65	.85	
Refrigeration	.7	.7	
Vacuum	.2	.6	
Controls + Computer	.35	.35	
Safety	.4	.4	
Plumbing	.4	.4	
	3.70	5.00	5.0

Charged Hadron Identifier Detector of relativistic rise of ionisation loss, scaled from 20 m^3 of ref. (4) to ~ 64 m^3 (Fig. 2)			2.5
Magnet Fe (~ 1600 tons	NAL Prop. 256 : Magnet Steel	307 $/ton	~2.0
	Ordinary low C.St.	250 $/ton	
	CERN Prop. P3: Carorim. Fe	1430 SF/ton	
	Shielding Iron ~	1000 SF/ton	
Coils (~ 100 tons of Cu)			2.0
Supporting structure etc.			0.5
Calorimeter (estimates from CERN SPS proposals P1 and P3			5.0
Cerenkovs, scintillators, wire chambers, etc.			2.0
Computer			1.0
			20. MSF

V) CONCLUDING REMARKS

A hybrid system satsifying all the five basic conditions stated on p. 2, if in fact technically feasible, would give essentially complete final state reconstruction for every event, including essentially complte particle identification. It would evidently yield a vast amount of extremely detailed information on $\Delta S = 0$ as well as $|\Delta S| = 1$ processes induced by ν_μ and ν_e and could be operated in a manner almost analoguous to Ω (hence the name "$\nu\Omega$"). It would have a very rich field of "bread-and-butter physics" open to it even in the absence of startling new discoveries.

But neutrino physics is still a relatively unexplored field. And despite the excitement generated by present theoretical developments, the new discoveries waiting to be made in neutrino physics may not be exactly those currently fashionable. (For example, neutral currents could have been discovered in a suitable apparatus in 1964. They were there. But one hunted the fashionable intermediate boson, which was not there). In this context we feel that the potential ability of such a device to completely reconstruct, analyse and understand every event is of paramount importance and that the requirement of high event rates, though important, is relatively subsidiary.

This question is of some importance because unfortunately the five basic requirements (p.2) are not all easily reconciled in a single apparatus. But if the reconstruction and analysing power of the apparatus is good enough, high statistics will eventually be accumulated in the course of time - especially when the SPS is eventually improved to deliver 10^{14} protons/pulse ! Neutrino experimenters have always felt plagued by low event rates. But surprisingly often at the end of the day the dominant errors have been systematic, not statistical. And event rates per ton of detector will anyway be some two orders of magnitude higher at the SPS than they have been at the PS. Our basic philosophy is therefore to look after the systematics and, in large measure, to let the statistics look after themselves.

Our final remark is a more general one. The fact that the SPS will come on the air only several years after NAL just means that considerable experimental and technical originality is required for the inevitably second generation experimental programme, if the aim is to do "first hand" experiments. The hybrid apparatus suggested here is certainly not cheap and has not yet been studied in detail. But we feel that it deserves more serious consideration than we have been able to give it. Our hope is that this note may at least prove to be a useful stimulus.

APPENDIX A

ANALYSIS OF STRANGENESS CHANGING INTERACTIONS

The analysis of $|\Delta S| = 1$ reactions and the search for $|\Delta S| > 1$ and $\Delta S = -\Delta Q$ interactions depends on how well single production of strange particles can be separated from associated production. Table A1 shows some of the associated production reactions easily confused with the corresponding single production reaction, if either a K^0 is not detected or a $K^{\pm}$ is not identified. H^0, H^-, H^+ represent any system of hadrons with total strangeness zero, total baryon number zero, and total charge zero, minus or plus respectively.

Physics interest			Reaction searched for	Some "background" reactions
$\|\Delta S\| = 1$ $\Delta S = \Delta Q$	Cabibbo angle energy dependent ?		$\bar{\nu}+p \rightarrow \mu^{+}+\Lambda+H^{0}$	$\bar{\nu}+p \rightarrow \mu^{+}+\Lambda+K^{+(0)}+H^{-(0)}$ $\bar{\nu}+n \rightarrow \mu^{+}+N^{*-}+\Lambda+K^{+(0)}+H^{-(0)}$
			$\nu+N \rightarrow \mu^{-}+N'+K^{0(+)}+H^{0(-)}$	$\nu+N \rightarrow \mu^{-}+N'+\bar{K}^{0}+K^{+}+H^{-}$
	relative rates test SU(6)	rel. rate tests $\Delta I = 1/2$	$\bar{\nu}+p \rightarrow \mu^{+}+\Sigma^{0}+H^{0}$ $\bar{\nu}+n \rightarrow \mu^{+}+\Sigma^{-}+H^{0}$	$\bar{\nu}+p \rightarrow \mu^{+}+n+\Lambda(\text{or}\,\Sigma^{0})+K^{+}+H^{-}$ $\bar{\nu}+n \rightarrow \mu^{+}+N^{*-}+\Sigma^{-}+K^{+}+H^{0}$
		"	$\bar{\nu}+p \rightarrow \mu^{+}+Y_1^{*0}+H^{0}$ $\bar{\nu}+n \rightarrow \mu^{+}+Y_1^{*-}+H^{0}$	$\bar{\nu}+p \rightarrow \mu^{+}+n+Y_1^{*0}+K^{+}+H^{-}$ $\bar{\nu}+n \rightarrow \mu^{+}+N^{*-}+Y_1^{*-}+K^{+}+H^{0}$
$\Delta S = -\Delta Q$ test (Charm search)			$\nu+p \rightarrow \mu^{-}+\Lambda+H^{++}$ $\nu+n \rightarrow \mu^{-}+\Sigma^{+}+H^{0}$	$\nu+p \rightarrow \mu^{-}+\Lambda+K^{+}(K_L^{0})+H^{+(++)}$ $\nu+n \rightarrow \mu^{-}+\Sigma^{+}+K^{+}+H^{-}$
$\|\Delta S\| > 1$ at high energy ?			$\bar{\nu}+n \rightarrow \mu^{+}+\Xi^{-}+H^{0}$ $\bar{\nu}+p \rightarrow \mu^{+}+\Sigma^{+}+K^{-}+H^{0}$ etc.	$\bar{\nu}+n \rightarrow \mu^{+}+\Xi^{-}+K^{+}+H^{-}$ $(\Delta S = 1)$ $\bar{\nu}+p \rightarrow \mu^{+}+\Sigma^{+}+\pi^{-}+H^{0}$ $(\Delta S = 1)$ etc.

Table 1A

It should be remembered that associated production will be as much as 15 to 20 % of the total cross section, whereas - in the absence of charm effects - the single production rates are $\lesssim$ 5 % ($\lesssim$ 1 %) in $\bar{\nu}$ (ν) interactions.

APPENDIX B

ANALYSIS OF NEUTRAL CURRENT INTERACTIONS

If the total hadron energy and the direction of the hadron jet (Fig. B1) are measured the scaling variable

$$u = x\,(1 - y) \simeq \frac{E_H \bar{\theta}_H^2}{2\,M}$$

can be used to test scaling even without complete event reconstruction $^{(10)}$.

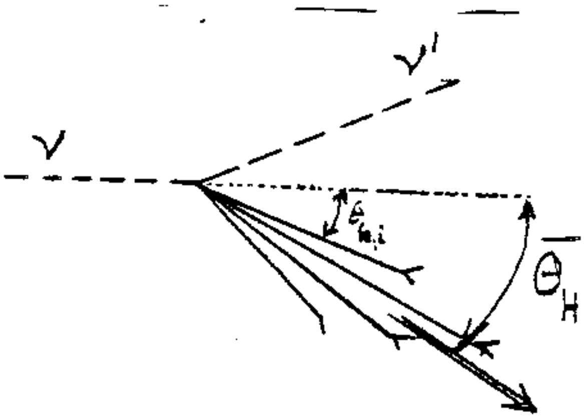


Fig. B1 Direction of hadron jet
$\bar{\theta}_H = \frac{1}{N} \cdot \sum_{i=1}^{N} \theta_{h,i}$

Energy of hadron jet $E_H = \sum_{i=1}^{N} E_{h,i}$

However, even in wideband beams neutral current events are 0-C in hydrogen if all secondary hadrons are detected identified and measured. So in principle one can calculate all kinematical quantities and obtain separate distributions in $x = \frac{Q^2}{2M\nu}$ and $y = \frac{E^H - M}{E^\nu}$, using longitudinal momentum balance

$$\ell \equiv E^{\nu'} - p_x^{\nu'} = M - (E^H - p_x^H) = p_x^H - \nu .$$

The magnitude of $\ell = x\,y\,M$ is generally 100 to 200 MeV. Its error can be a few MeV, if all hadrons are detected, identified and measured, but 100 % or more in case of missing neutrals, mis-identification of hadrons, or interactions in nuclei (Fermi momentum).

Using $Q^2 = -q^2 = -(\nu^2 - p^{H2}) - p_t^{H2} + 2\,p_x^H\,\ell - \ell^2 = 2\,\ell(p_x^H - \ell) + p_t^{H2} + \ell^2$

$$E^\nu = Q^2/2\,\ell = p_x^H - \ell + (p_t^{H2} + \ell^2)/2\,\ell$$

and assuming the usual case : $\ell \ll p_x^H$, $\ell^2 \ll p_t^2$, one can easily show that the errors in E_ν, y and Q^2, x are

$$\frac{\Delta E_\nu}{E_\nu} \; , \; \frac{\Delta y}{y} = (1 - y) \, . \, \frac{\Delta \ell}{\ell} = \frac{1 - y}{xy} \, . \, \frac{\Delta \ell}{M}$$

$$\frac{\Delta Q^2}{Q^2} \; , \; \frac{\Delta x}{x} = y \, \frac{\Delta \ell}{\ell} = \frac{1}{x} \, . \, \frac{\Delta \ell}{M}$$

if ℓ is the only badly measured quantity. We can write ℓ as $M - \sum_{i=1}^{n} \left((m^2 + p_t^2) \, / \, (E + p_x) \right)_i^h$. All quantities thus depend critically for their evaluation on the condition that no hadron is missed or mis-identified.

In narrow band beams one could alternatively try to get ℓ by working backwards from the beam energy E_ν (known to 5 to 10 %). Then

$$\frac{\Delta \ell}{\ell} = \frac{1}{1 - y} \; \frac{\Delta E_\nu}{E_\nu}$$

and

$$\frac{\Delta Q^2}{Q^2} = \frac{y}{1 - y} \; \frac{\Delta E_\nu}{E_\nu}$$

i.e. Q^2- distributions would be useful only in a very limited range.

Hence, in order to measure Q^2 distributions over a wide Q^2-range it seems imperative to use a detector which allows complete final state reconstruction, and then wideband neutrino beams can be used.

APPENDIX C

EXPECTED ν ($\bar{\nu}$) FLUXES

Fig. C1 shows the neutrino and antineutrino fluxes assumed for the rate estimates in section III. They were calculated for 400 GeV/c protons using a simple design extrapolation of the present CERN neutrino beam for 26 GeV/c protons (11). Presumably higher fluxes could be obtained by detailed optimization, especially by matching horn shape and current to the measured angle and momentum distribution of pions and kaons produced by 400 GeV/c protons.

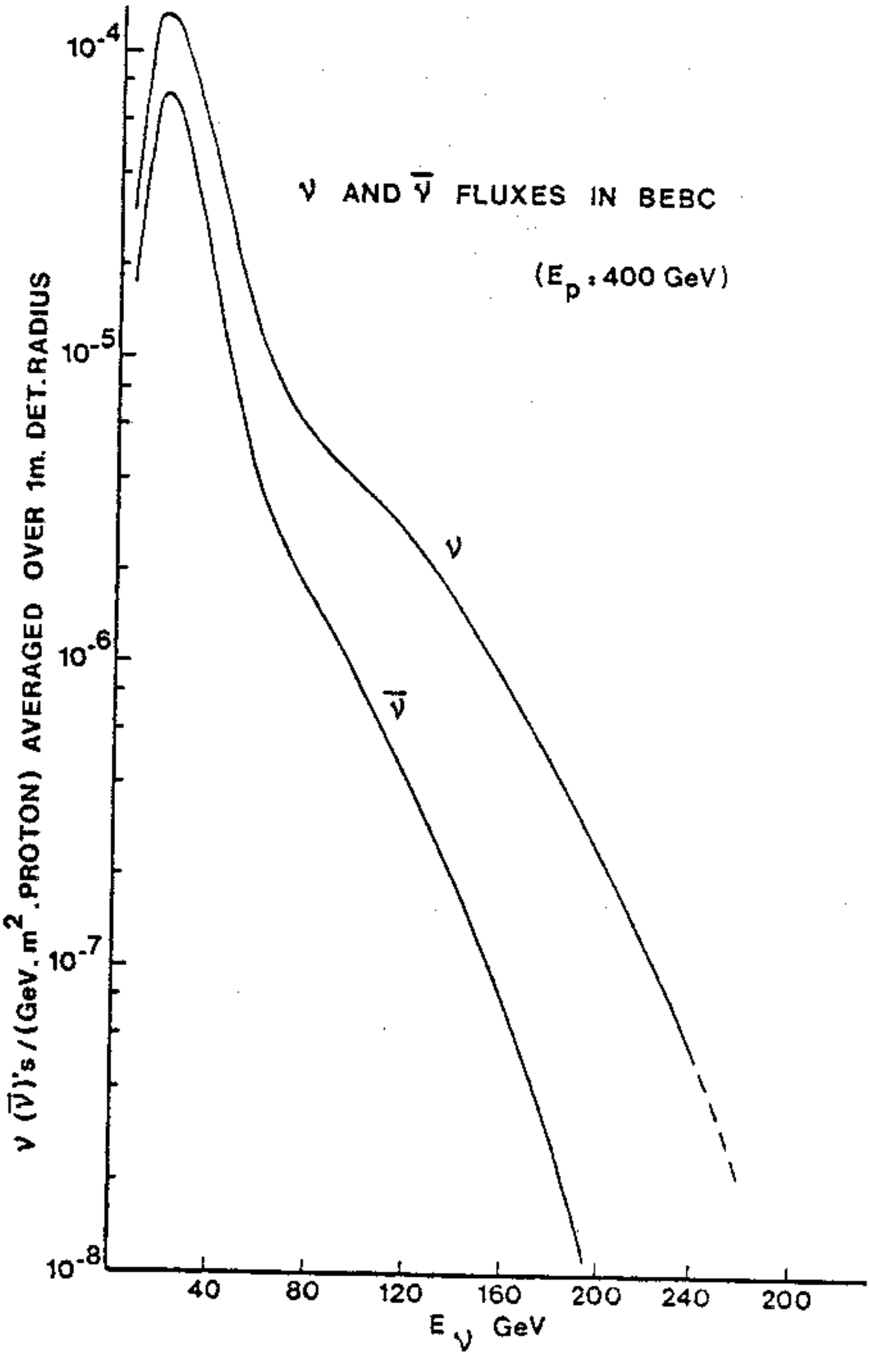


Fig. C1

APPENDIX D

Compilation of some neutrino physics results or predictions

As a guide-line to design in grater detail a hybrid apparatus, best information about expected event rates, particle multiplicities and kinematical behaviour of hadrons and leptons should be used.

Cross-sections are compiled in Fig. D 1. Numbers user for rate estimates are :

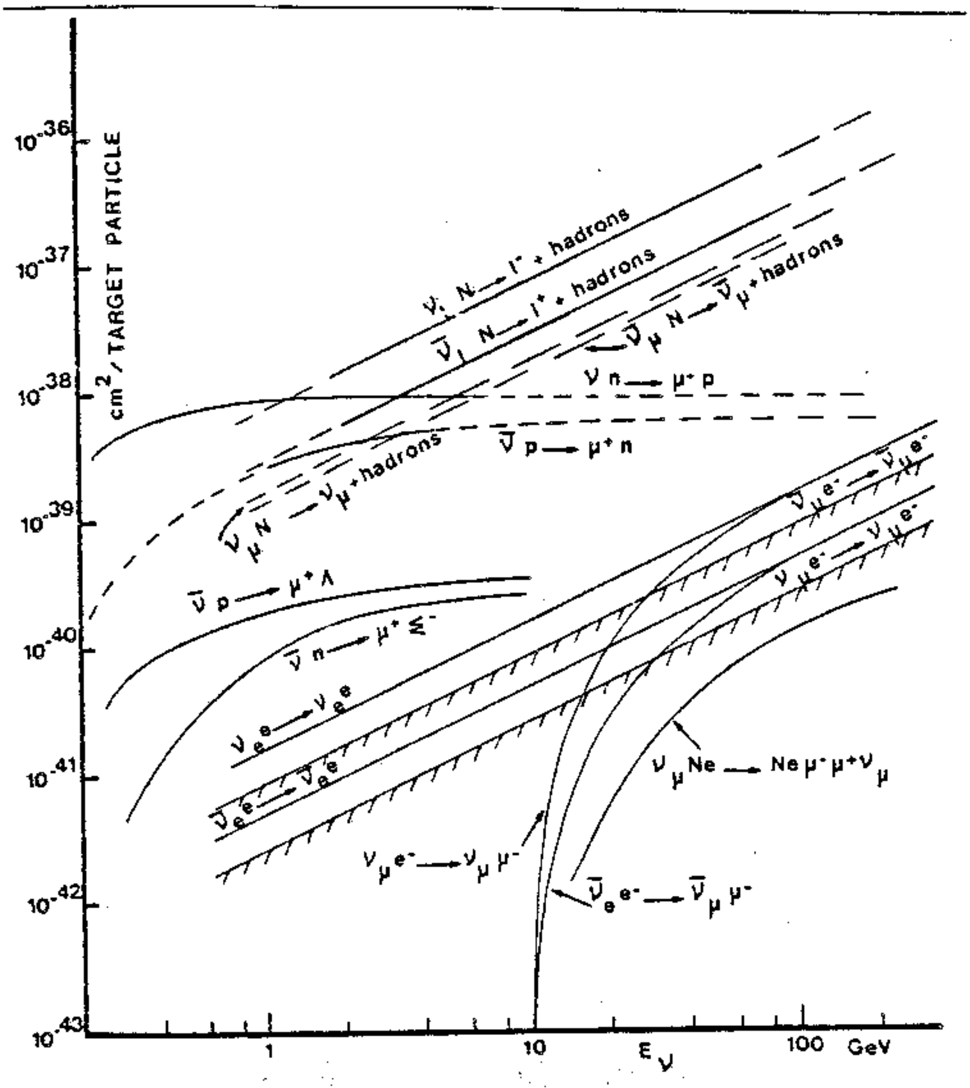


Fig. D1

$$\sigma^{\nu_\mu}_{tot} = .8 \times 10^{-38}\, E_\nu\ cm^2/GeV$$

$$\sigma^{\bar{\nu}}_{tot} = .35 \times \sigma^{\nu}_{tot}$$

$$\sigma^{\nu_\mu} = \sigma^{\nu_e}$$

(μ - e universality)

The quark parton model predicts

$$\sigma^{\nu n} : \sigma^{\nu p} : \sigma^{\bar{\nu} p} : \sigma^{\bar{\nu} n} = 6 : 3 : 2 : 1$$

Strange particle production according to quark parton model :

$$\frac{\sigma^{\nu N}(|\Delta| = 1)}{\sigma^{\nu N}_{tot}} \lesssim 1\ \% , \quad \frac{\sigma^{\bar{\nu} N}(|\Delta S| = 1)}{\sigma^{\bar{\nu} N}_{tot}} \lesssim 5\ \%$$

which is not in contradiction with first Gargamelle results. At higher energies charmed particle models would predict also in neutrino interactions up to 5 % strange particle production rates. Associated production of strange particles seems to increase with neutrino energy (13) and could be as high as 20 % above 10 GeV (14).

Neutral current interactions :

a) $$\frac{\nu + N \rightarrow \nu + H}{\nu + N \rightarrow \nu + \mu + H} = \begin{cases} .2 ; & \nu \\ .4 ; & \bar{\nu} \end{cases}$$

b) $$.10 < \sigma^{\nu_\mu e} < .96 \times 10^{-41}\ E\ cm^2/(GeV.e)$$

$$.11 < \sigma^{\bar{\nu}_\mu e} < 1.78 \times 10^{-41}\ E\ cm^2/(GeV.e)$$

Charged hadron multiplicities seem to increase logarithmically with the invariant mass of the hadron system, ranging from 1 to 5 in present heavy liquid neutrino experiments ($1 < E_\nu < 16$ GeV). First scanning results from the NAL-15-foot-H_2-bubble chamber ν experiment at 300 GeV indicate $<n_{ch}> \sim 5$ between 10 - 30, ~ 7 between 100 - 300 GeV ( ).

Kinematical behaviour of final state particles will be obtained from analysis of NAL bubble chamber neutrino experiments. At present Monte Carlo calculations using simple parton models and hadron transverse momentum distributions from hadron-hadron-collisions ($p_t \sim e^{-6\ pt}$) can be used to estimate acceptances. One such result (15) is reproduced in Fig. D 2.

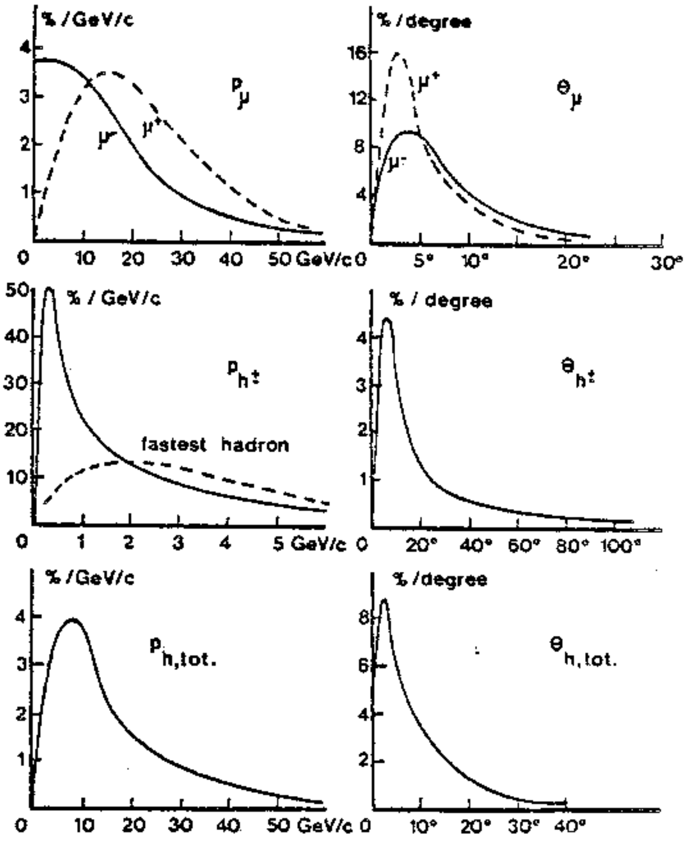


Fig. D 2 (reproduced from ref. 15)

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