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EXPERIMENTAL USE OF THE 200 GeV ACCELERATOR

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The "extendible energy" feature developed at Berkeley in 1966 will be incorporated and the radius of the machine has been increased from 700 m to 1000 m to allow an ultimate capability in energy of 400 GeV. Other changes include: the choice of a separated-function rather than a combined function lattice, a substantially smaller tunnel cross-section, an H-magnet instead of a C-magnet, concentration upon a single extracted beam rather than two, and a reduced internal beam target area. Professor Wilson has announced his desire to have a beam by the middle of 1972.

It is expected that funding in the neighborhood of 240 M$ (excluding equipment) will be approved by the government. Whether this money will become available next year is a question at present under consideration and the answer will not be known for some months. On the one hand the present cut-backs on money for research may cause a delay, while on the other hand, the publicity associated with the successful starting of the Serpukhov 70 GeV accelerator may cause the plans to be pushed ahead quickly.

III. Use of the Accelerator

What can be done with an accelerator depends essentially on the particles produced by the accelerator and on their fluxes. Figure 1 shows the fluxes, dn/dp, of π^+ and π^- mesons, as calculated according to the Trilling model, that will be produced by primary protons of energy 30 GeV, 70 GeV and 200 GeV. Thus the AGS has useful secondary beams up to about 20 GeV, Serpukhov up to about 50 GeV and the 200 GeV machine up to about 140 GeV. Note however that the normalization is in terms of pions per interacting proton and the intensity of the accelerator must be taken into account in computing fluxes. In 1971 the AGS will have an intensity of about 10^{13} protons per second and a few years later so also will the 200 GeV accelerator. The 70 GeV accelerator will be about one order of magnitude lower in intensity and it is probably not too soon to begin to think of how the intensity should be increased.

An interesting experiment to measure fluxes of high energy particles produced in p + p collisions, with rather simple apparatus, is described by Jovanovič. This relies on the fact that in the Center-of-Mass System (CMS) particle production will be symmetrical between the forward and backward direction. In the Laboratory System (L.S.) the forward-going particles will be highly energetic but their CMS momentum spectrum will be reflected by the slow backward-going particles (less than 500 MeV/c for pions). Thus a very simple low energy spectrometer looking in the backward direction to a hydrogen target can provide a great deal of information about the very energetic particles.

Ideally, the goal of elementary particle experimental physics should be to measure the interaction of each known particle with every other known particle. In practice the situation is much more limited both in the target particles and the beam particles available in the laboratory. One is essentially confined to the following choices:

Target particles: p, e, (n), (γ), (neutron not free, γ-ray target very rare)

Beam particles: p, $\bar{p}$, $K^{\pm}$, $\pi^{\pm}$, $e^{\pm}$, γ, Y(Λ^{0} $\Sigma^{\pm}$ Ξ Ω), K^{0}, n, ν, μ.

During the design of the accelerator many physicists have collaborated in devising experiments using these particles and in making preliminary beam designs. This is important to consider at an early stage to ensure that the accelerator itself can be flexibly adapted to serve various experimental demands and that the experimental areas will be of adequate size and shape. Also such considerations allow one to estimate the quantity and nature of experimental equipment needed. For convenience, the more standard beams of p, $\bar{p}$, $\pi^{\pm}$, $K^{\pm}$ are treated separately from the others which require rather special solutions.

IV. Standard Beams (p, $\bar{p}$, $\pi^{\pm}$, $K^{\pm}$)

These particle beams are usually produced by either electronic identification (counters) or else by spatial separation.

a) Counter beams: Both threshold and differential (e.g., DISC-type) Čerenkov counters will be useful and practicable over the whole energy range at the 200 BeV accelerator for electronic identification of particles.

Differential counters will require accurately parallel beams and may not be suitable for maximum intensities at the higher energies. A special consideration is the very large p/π^+ ratio that will be encountered at the higher energies. Examples of experiments that are considered for such beams are:

(i) Total cross sections (Pomerančuk Theorems and Dispersion Relations).

(ii) Elastic and charge-exchange scattering (Regge Poles).

(iii) Pion form factor. The interpretation of the π–e scattering experiment discussed by Toohig may be complicated by the fact that several diagrams may contribute. On the basis of a simple form factor involving the ρ-meson mass one expects the following deviations from "point charge" behavior:

E_π (Gev)	T_{max} (electron)	Max Momentum Transfer (GeV^2)	Deviation
50	36 GeV	.036	11%
100	84 GeV	.084	25%

(iv) Search for massive stable particles: The pair production of massive particles (e.g., quarks) through the reaction:

$$p + p \rightarrow p + p + X + X'$$

where $M(X) = M(X')$ has been considered by Chinowsky. If the target is a free proton the maximum mass, M(X), kinematically produced is 9 GeV/c^2 at 200 GeV and about 5 GeV/c^2 at 70 GeV. If the target proton is bound in a nucleus the effect of the Fermi momentum is to increase the kinematically allowed mass. Chinowsky estimates that the detectable value of M(X) for production from a heavy target may be 13 GeV/c^2 at 200 GeV and 7.5 GeV/c^2 at 70 GeV.

b) Spatially Separated Beams ($p\ \bar{p}\ \pi^\pm\ K^\pm$):

(i) A scheme for producing a separated beam of particles proposed by Veksler involves the introduction into the accelerator structure of a high-frequency cavity to bunch the circulating beam. At the 200 GeV machine a 3 GH_z cavity about 10 m long would seem to be adequate (Lamb). There will be ample space reserved in the accelerator lattice to allow such a device to be inserted. The proton beam bunched at this frequency then strikes a target to produce a secondary beam modulated at the same frequency. Some distance downstream a transversely-deflecting cavity correctly phased can deflect wanted particles in a chosen direction. Alternatively a counter beam can be constructed by using, instead of a second cavity, an r-f modulated photomultiplier (3 GH_z) similar to that recently developed at LRL by J. J. Murray.

(ii) R-F Separated Beams. There is a rather detailed preliminary design by Lach for a three-cavity r-f separated beam with a design momentum of 100 GeV/c for kaons. The distance between the first and second cavities is 250 m and between the second and third 450 m. The operating frequency is 10 GH_z and the cavities would probably be superconducting. Thus the duty factor could be long and the beam could be used by counter experiments as well as bubble chambers if a suitable switch-yard were built at the tail-end of the beam.

The cavities in Lach's beam were assumed to be of the standard linearly-polarized type, viz., to have a transverse electric field, constant in direction. The practice in this case is to arrange for the net deflection of the two unwanted particle components (e.g., π and p) to be zero and that of the wanted particles (e.g., K) to be non-zero. Thus the unwanted particles can be caught on a "beam-stopper" and most of the wanted particles miss the stopper and can be transported on to the detector. In another report Sandweiss has pointed out the advantage of using a circularly polarized deflector. This might consist of two linearly-polarized cavities close together with a phase difference of 90°. In this case the net deflection of the wanted particles (K) would be arranged to be zero and the net deflection of the unwanted particles (π,p) would, in general, be non-zero. This is a less restrictive condition than in the previous case. The undeflected K's would finally pass through a small hole in a collimator and the cones of π's and p's would be stopped in the surrounding material. Sandweiss has made a direct comparison of the circularly- versus linearly-polarized systems assuming the same cavity spacing as in Lach's beam and the result is shown in Fig. 2. The advantages of the use of circular polarization are clear -

the deflections are increased, the stop bands diminished and the upper limit in momentum extended.

(iii) Pulsed Magnet Separator. The possibility of using Čerenkov counters to identify certain chosen particles and thereby to deflect these particles selectively into a detector, e.g., bubble chamber was proposed about 1961 by Brody. Recent developments in rapidly-pulsed kicker-magnets and laser-triggers for spark gaps has renewed interest in this suggestion. Kadyk has examined how such a beam could be constructed using present-day technology. (See Fig. 3.) It is necessary for the beam particles to travel in a longer path than the light signal from the counter to the pulsed magnet in order to make up for the unavoidable electronic delays. If these delays are 40 nsec and the total beam length 300 m, then the angle of bend need be only about 30 deg. Such a separated beam for bubble chambers at high energies has important advantages: it is relatively cheap and the beam optics need not be as precise as in other types of separated beams.

V. Special Beams (K^o, n, Y, $e^{\pm}$, γ, ν, μ)

a) Neutral Beams (K^o, n): There is a discussion in a report by Read of the ratios of different particles in neutral beams produced close to the forward direction (0–10 mrad). In particular he describes how a K^o beam might be constructed. Bending magnets can remove the charged particles while lead absorbers followed by bending magnets can eliminate the γ-rays. In order to decrease the neutron-to-kaon ratio Read proposes the use of a long polyethylene absorber. The absorption cross-section of K^o in CH_2 is approximately 0.6 times that of neutrons so that the neutrons are preferentially absorbed. (Liquid hydrogen would also be a suitable absorber.) The flux of K^o is, of course, reduced by this process so that in a particular experiment one must compromise between the flux required and the purity of the beam. Also discussed is an experiment to measure $[\sigma_T (K^o p) - \sigma_T (\overline{K}^o p)]$ in the region of 50 GeV/c by studying coherent regeneration. The difference in the total cross-sections can be measured quite accurately and is interesting in the study of the asymptotic behavior.

b) <u>Hyperon Beams</u>: At very high energies the lifetime of hyperons is long enough that they can travel several meters, thus opening up the possibility of constructing hyperon beams. Longo has suggested making a Λ^0 beam of relatively small energy spread by utilizing the decay of

$$\Xi^- \rightarrow \Lambda^0 + \pi^- .$$

Negative particles produced in an external target are selected and roughly analyzed in momentum by a bending magnet. The beam next travels over a drift space of a few meters – during which the Ξ^- hyperons decay – and is then bent sharply away from the detector. The kinematics of the decay are such that the Λ^0 travels closely parallel to the direction of the parent hyperon and furthermore will have an energy spread of only about 20%. Because of the large background of neutral particles from other hyperon decays (e.g., n, $\bar{n}$) it is necessary in an experiment on elastic scattering, $\Lambda^0 p \rightarrow \Lambda^0 p$, to detect the final-state Λ^0 as an additional check.

The possibility of studying the interactions of Ξ^--hyperons in hydrogen has been examined by Cook. He considers the Ξ^- particles to be produced in the reaction:

$$K^- + p \rightarrow K^+ + \Xi^- .$$

Thus an intense K^- beam is allowed to strike a liquid hydrogen target and a counter and spark chamber telescope is arranged to detect the production of the K^+ meson. In addition, a Čerenkov counter detects the Ξ^- particle which enters a liquid hydrogen target 2–3 meters downstream of the production point. Spark chambers are placed behind the hydrogen target to detect the scattered proton and hyperon and to observe the Ξ^- decay, to $\Lambda^0 + \pi^-$. Cook concludes that the rate of events will be very small and that this is a very difficult experiment.

When high energy hyperon beams are constructed they will certainly rely heavily on high-field superconducting beam transport magnets. Also, counters to help in the identification of the hyperons must be very compact. Čerenkov counters may be too long and it seems likely that counters using the Ter-Michaelyan effect, or perhaps secondary-electron-emission counters that can measure velocity, will be essential to use.

c) Electron and Photon Beams: There are extensive discussions by Heusch of the methods of creating useful beams of electrons, positrons and photons at high energies, and also of the useful physics for which they could be used. Electron or positron beams with small momentum spread at 100 GeV could have intensities in the region 10^6 to 10^8 per pulse depending on the purity desired. Photon beams at the same energy should have intensities of about 10^7 sec^{-1} GeV^{-1}. These intensities are not high enough to carry out experiments involving very small cross sections such as are at present often performed at electron linear accelerators. But the energies available far transcend those available at any electron accelerator existing or even planned, and there are many useful experiments involving reasonably large cross sections that should be performed. Among these are studies of positron annihilation, wide-angle pair-production, wide-angle bremsstrahlung, production of strongly-interacting particles (to examine the behavior of the Drell, diffraction, and one-pion-exchange mechanisms), photo-production of π^+ and π^0 mesons from hydrogen and total cross sections for γp and γn.

Čerenkov counters can be used to obtain very pure electron beams for intensities $\leq 10^6$ sec^{-1}. Heusch has drawn attention to the usefulness of tagged photon beams. In this case an intense - but not necessarily pure - electron beam of defined momentum is allowed to strike a lead radiator. If bremsstrahlung occurs, the degraded electron has its final momentum measured by means of a magnetic hodoscope spectrometer and its identity as an electron verified by means of shower counters (See Fig. 4). Thus the energy of the radiated photon can be determined. An extension of the streamer-chamber technique as used by Mozley at SLAC would seem to be very useful.

d) Neutrino and Muon Beams: Systems for the production of neutrino beams hitherto used at present accelerators may be called "broad-band" systems, namely, both the neutrinos and the charged particles in the beam extend in energy all the way from zero up to the maximum energy of the primary photon beam. Disadvantages of the "broad-band" system include the gross uncertainty in the energy of the neutrino initiating a certain reaction in the detector, and the need for a shield in front of the detector to absorb the highest energy muons produced. In the case of the 200 GeV accelerator the shield thickness needed to absorb a 200 GeV muon would be about 100 meters of iron.

It has been proposed that a so-called "narrow-band" system might be used at the 200 GeV accelerator. In such a system a charged secondary-particle beam containing π-mesons and K-mesons would be selected in momentum and steered down a long straight strong-focussing channel consisting of distributed quadrupoles. The mean decay length for pions is (55 p) meters and for kaons is (7.4 p) meters, where p is the particle momentum in GeV/c. In travelling down the channel - approximately 1000 meters long - the decays $\pi \to \mu + \nu$ and $K \to \mu + \nu$ take place and the more energetic neutrinos will travel forward and enter the detector placed at the end of the channel. The energy spectrum of the neutrinos is peaked towards the upper kinematical limit and its exact shape depends on the length of the decay channel and the diameter of the detector. Figure 5 shows some examples for a detector diameter of 6 meters and for two different channel lengths and two energies. Note that for a given energy of the charged particle beam, pions can give rise to neutrinos of at most about half that energy whereas kaons can give neutrinos of almost the full energy.

The importance of the K-meson decays as a source of high-energy neutrinos is illustrated in Figure 6. These curves refer to a channel 1000 meters long and refer to detectors with different values of radius, R. The ordinate is the number of neutrinos between 80% and 100% of the kinematically maximum energy in either π-decay or $K_{\mu 2}$ decay according as the channel is tuned for different charged particle momenta. It is clear that above neutrino energies of about 35-40 GeV the $K_{\mu 2}$ decays are the predominant source of neutrinos.

With an intensity of 3×10^{13} protons per pulse the 200 GeV accelerator should be able to produce several neutrino interactions per pulse in a hydrogen bubble chamber of 100 m^3 volume. The rate of elastic interactions should, however, be substantially less than one per pulse.

Because the neutrino beam and the r.f. beam are both very long ($\gtrsim$ 1000 meters) and should both serve a large bubble chamber, the arrangement shown in Figure 7 is proposed. Here the bubble chamber is located in a separate experimental area far from the main target station. The bubble chamber is located directly in line with the neutrino beam and behind it may be placed counter and spark chamber arrays also to perform neutrino experiments. By means of switching magnets the radiofrequency-separated beam may be diverted either to the large bubble chamber or to a counter experiment.

By proper design of the channel a large fraction of the high-energy μ-mesons arising in π-decay can be captured and retained in the channel until the end. Here they can be switched away from the neutrino direction by means of a magnet, and purified in a strongly interacting particle filter. Approximately 10^8 mu-mesons per pulse in a 1% momentum interval at 20 GeV can be obtained in this way.

LIST OF FIGURES

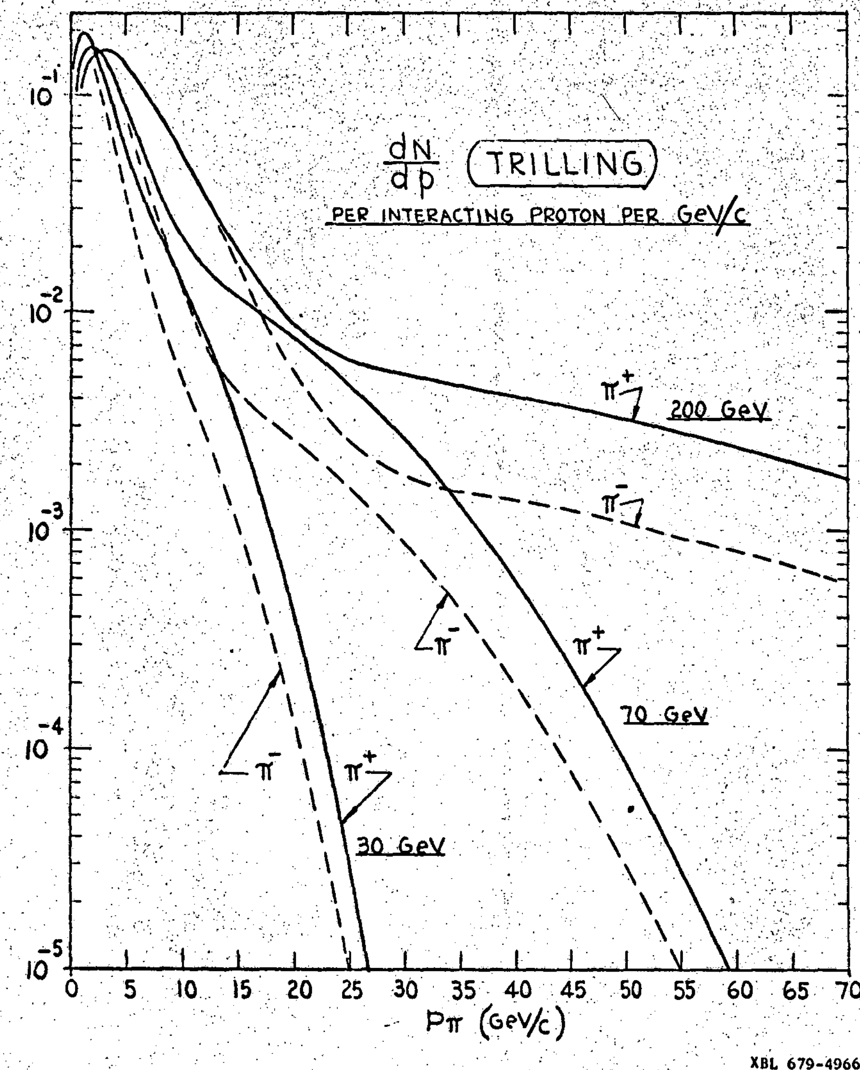
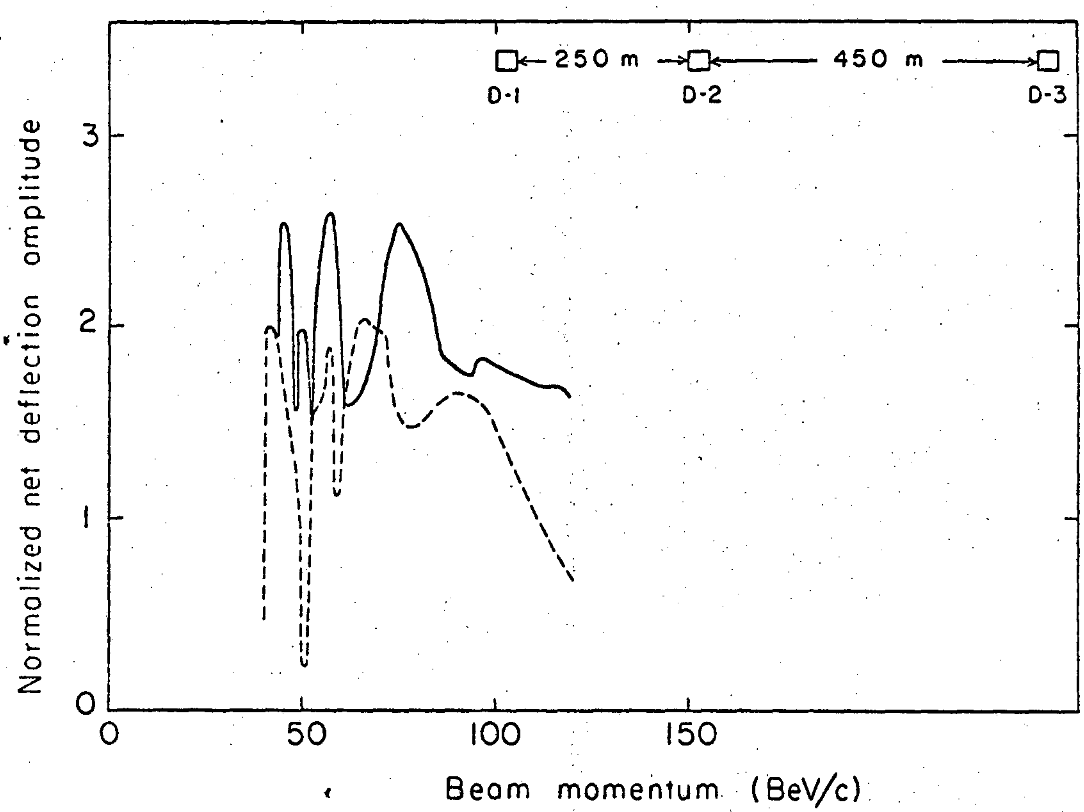

dN/dp (TRILLING)
PER INTERACTING PROTON PER GeV/c
π+
200 GeV
π-
π-
π+
70 GeV
π-
π+
30 GeV
10^-1
10^-2
10^-3
10^-4
10^-5
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Pπ (GeV/c)
XBL 679-4966

Fig. 1



XBL 671-513

Fig. 2

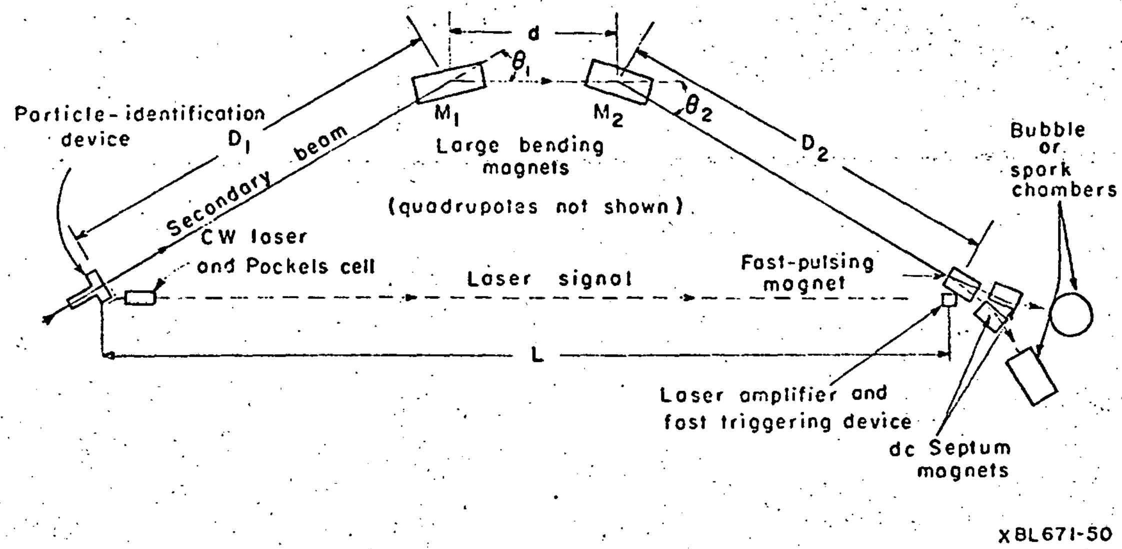
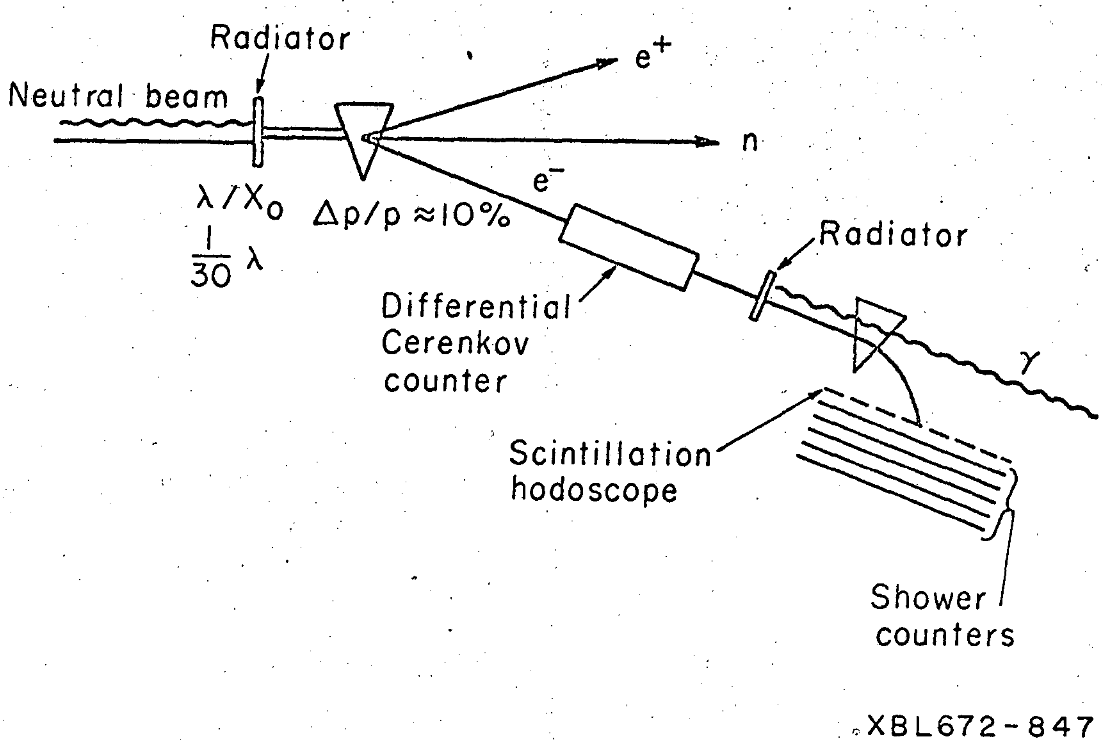
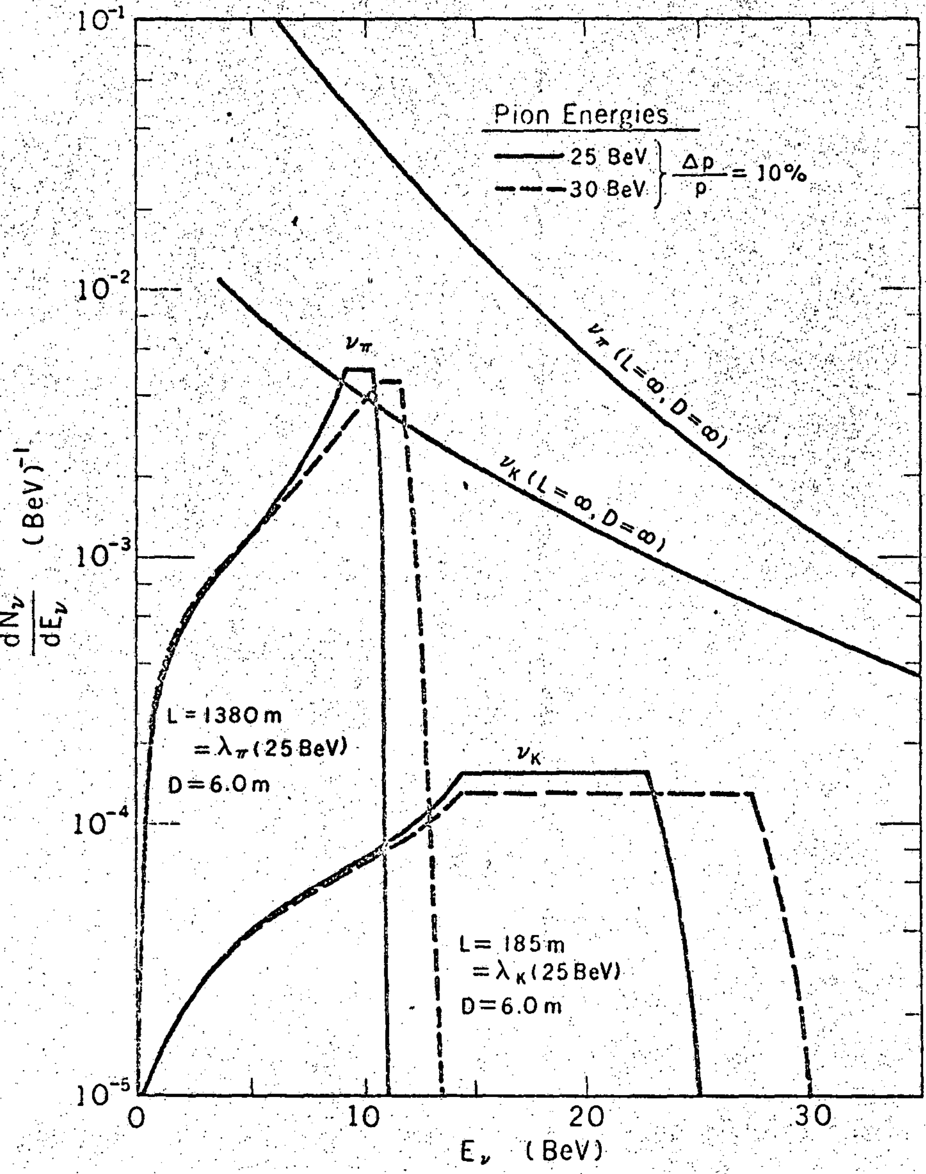

d
θ_1
θ_2
M_1
M_2
Particle-identification device
D_1
Secondary beam
Large bending magnets
(quadrupoles not shown)
D_2
Bubble or spark chambers
CW laser and Pockels cell
Laser signal
Fast-pulsing magnet
L
Laser amplifier and fast triggering device
dc Septum magnets
XBL671-50

Fig. 3



Radiator
Neutral beam
e+
n
e−
λ/X0
Δp/p ≈10%
1/30 λ
Radiator
Differential
Cerenkov
counter
γ
Scintillation
hodoscope
Shower
counters
XBL672-847

Fig. 4



Neutrino Flux Per Interacting Proton

Fig. 5

MUB-6407

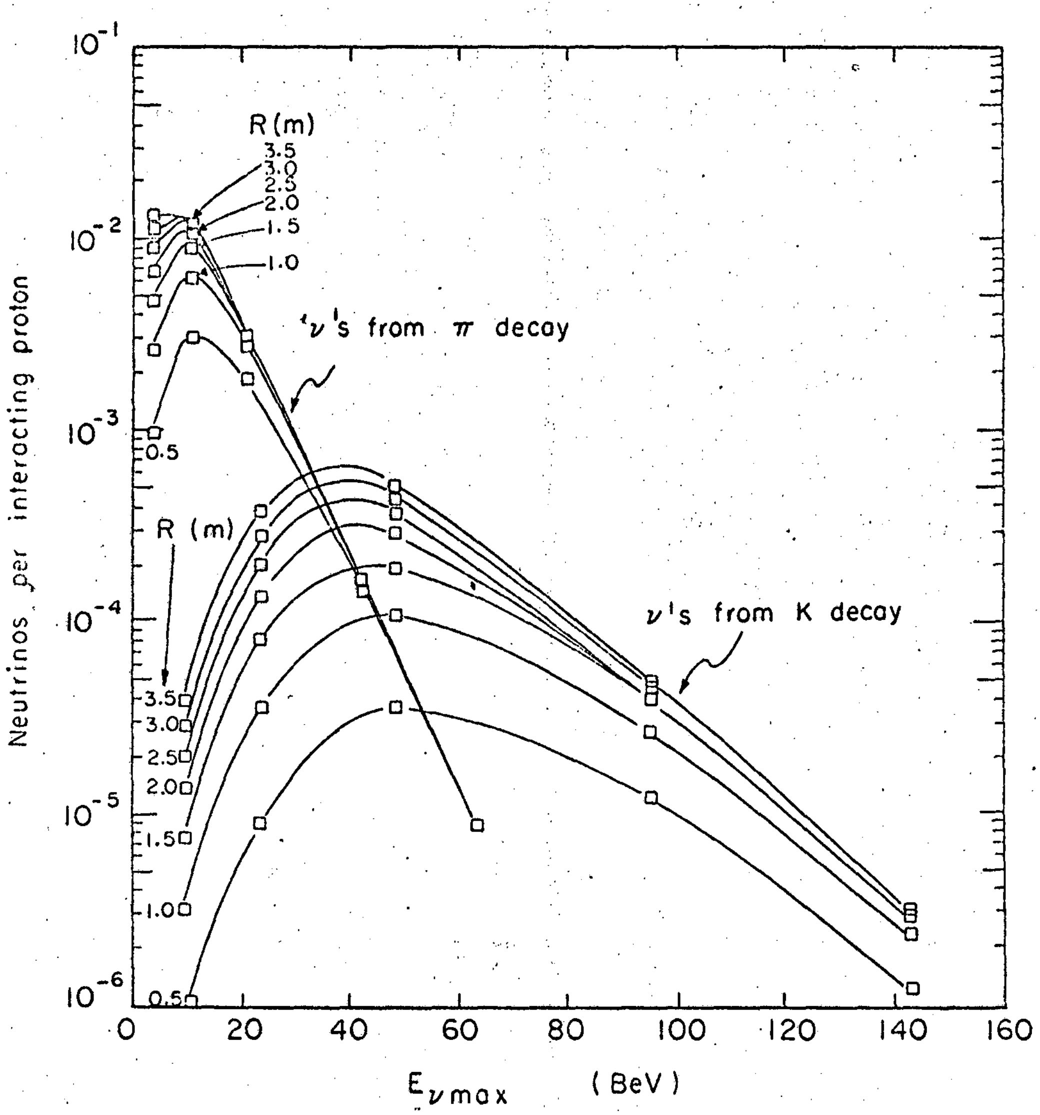
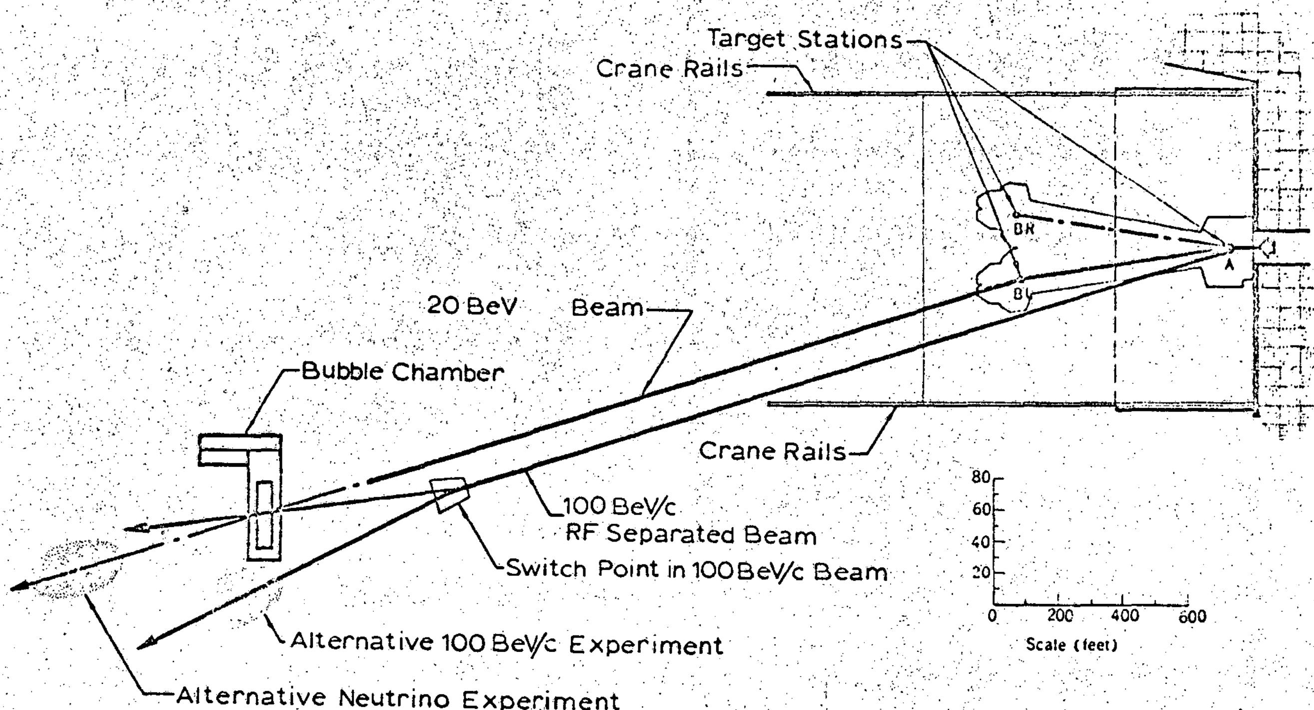

R (m)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ν's from π decay
ν's from K decay
R (m)
3.5
3.0
2.5
2.0
1.5
1.00
0.5
Neutrinos per interacting proton
E$_{\nu max}$ (BeV)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
20
40
60
80
100
120
140
160
XBL671-323

Fig. 6



Dual-Beam Facility for Bubble Chamber in "Long E.P.B." Area "J"

MUB-7197

Fig. 7