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Expression of Interest in a Very Long Baseline Neutrino Oscillation Experiment

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Contents

1 Introduction

Among the most challenging open questions in particle physics are

- do neutrino flavors mix, and
- are neutrinos massive.

The question of the existence of dark matter is strongly linked to the possibility of massive (30 eV) neutrinos.

Present theoretical views favor the ν_τ as the heaviest neutrino, provided neutrinos are not massless. Experimentally, this fundamental question can and has been investigated by searching for ν_μ–ν_τ oscillations. With the advent of a ~1 megaton water Čerenkov detector (GRANDE) sited near Little Rock, Arkansas and the decision to site the SSC at a distance of ~400 km, near Dallas, a new domain of neutrino oscillation parameters, unexplored until now, can be studied.

The simplest methods for searching for oscillations would be to look for $\nu_\mu \to \nu_x$ disappearance by examining either the neutral- to charged-current ratio or the charged-current rate at two different distances. Neglecting systematic errors, these methods would provide sensitivity in $\sin^2 2\theta$ at about 0.005. The sensitivity in Δm^2 at maximum mixing, as determined by L/E, would be as low as 0.003 eV^2.

This region of neutrino mass is completely unexplored and of great theoretical interest. The "see-saw" mechanism[1,2] for neutrino mass generation predicts that the ratios of neutrino masses follow the corresponding ratios (or ratios-squared) of lepton masses. If the solar neutrino deficit is due to the MSW effect, it follows that $m_{\nu_\mu} \sim 10^{-2}$ eV. Then, $m_{\nu_\tau} \sim 0.17$ to 2.9 eV if the ratio or ratio-squared of lepton masses is taken. Thus, $\Delta m^2_{\mu\tau} \sim 3 \times 10^{-2}$ to $8eV^2$. It has also been suggested that the neutrino mixing matrix should be the same as the quark (KM) mixing matrix[3]. Thus, it is expected that $\sin^2\theta_{\mu\tau} \simeq 5 \times 10^{-3}$ to 1×10^{-2}. Only an accelerator experiment with L/E in the range provided by the SSC–GRANDE combination can explore this very interesting region of parameter space.

A rough comparison of the capabilities of SSC–GRANDE and other neutrino oscillation experiments sensitive to ν_μ disappearance can be made:

Using L/E (km/GeV) as a guide to Δm^2 sensitivity, with larger L/E representing better sensitivity, current experiments at other accelerators operate in the range 0.025 to 0.7. SSC–GRANDE can reach an L/E value as high as 20. Statistical and systematic uncertainties limit the sensitivity in $\sin^2 2\theta$. Typical accelerator experiments reach to $\sim 5 \times 10^{-3}$ to 2×10^{-2}. The statistical uncertainties for SSC–GRANDE will limit $\sin^2 2\theta$ to about 5×10^{-3} with systematics being the limiting factor.

We are interested in exploring this new opportunity by searching for the appearance of ν_τ's in a beam of high energy ν_μ's. This beam would be produced by protons of 200 GeV energy extracted from the 200 GeV Medium Energy Booster (MEB) and directed and focused onto a 200 cm long beryllium target. The beam must be pointed towards GRANDE. Positively charged secondaries would be focused by a toroidal horn and a reflector to enhance the muon neutrino flux from π^+ and $K^+ \rightarrow \mu^+\nu$ decays. The extraction scheme and the neutrino beam are described in Section 2.

The appearance of a ν_τ component (or an enhanced ν_e component) in the beam could be searched for by measuring the ratio of muonless events (called "NC") to events with a muon (called "CC"),

$$R = \frac{N\,(NC)}{N\,(CC)}.$$

R may be measured in several different ways. Two methods that we have investigated thus far are:

- *Using two detectors*, a close detector of ~30 tonnes fiducial mass at 1km distance and a far detector, GRANDE, ~1 megaton mass at 400 km distance. The two event topologies, NC and CC, will be defined by using the so-called event length method[4,5] (see Section 4.1). 83% of tau decays do not have a muon in the final state, and these will be classified as "NC" events . Hence, $\nu_\mu - \nu_\tau$ oscillations will reduce the number of CC events and add to the number of NC events. By using a two-detector scheme with identical structure and detection efficiency we can perform relative measurements of R where the systematics (yet to be analyzed) will largely cancel. The statistical accuracy is expected to correspond to a sensitivity of

$$| U_{\mu\tau} |^2 < 10^{-3} \qquad (90\%\text{c.l.})$$

for $\Delta m^2 \gtrsim 0.07 eV^2$ (see also Section 4), where $|U_{\mu\tau}|^2$ ($= \sin^2 2\theta$) is the matrix element of the mixing matrix describing $\nu_\mu - \nu_\tau$ mixing. (This sensitivity could be improved by additional running time.) The present limit is $|U_{\mu\tau}|^2 < 4 \times 10^{-3}$ for $\Delta m^2 > 10\ eV^2$ [6].

- *Using a single detector*, at 400 km. In this technique (see Sect. 4.2) R is analyzed as a function of energy deposited in the detector. The statistical accuracy is expected to correspond to $|U_{\mu\tau}|^2 \gtrsim 7 \times 10^{-3}$ for $\Delta m^2 > 0.06\ eV^2$.

The detectors are described in Section 3.

Cost estimates are given in Section 5.

2 The Neutrino Beam

A 200 GeV proton beam can be directed towards GRANDE by either

- splitting the proton beam ejected from the MEB at M4 towards the HEB (beam line 2) and deflecting it by $\sim 20°$, or
- by combining the injection into the MEB at M5 with a new slow-fast ejection; this latter scheme has the advantage that it can operate together with test beams from the HEB and that it requires less bending power.

Both schemes (see Fig. 1) appear feasible and we would favor the second one because of its operational advantages. Data taking would require 2×10^{19} protons on target achievable as main user in 25 days of operation with 100% efficiency. A typical data run of 100 days would require only parasitic running with 25% of the protons devoted to this experiment.

The layout of the beam line with additional bending (horizontal and vertical) is shown in Figure 2. The proton beam travels in a vacuum pipe and must be focused to a spot of $\sigma \sim 1$ mm to match a beryllium target of 3 mm diameter. The target is composed of 10 rods of 10 cm length each, spaced by 10 cm to allow small angle pions and kaons to escape and to be focused. Two focusing elements, a horn and a reflector, are pulsed with currents of $\sim$ 50 KA. A decay region of 300 m length and 1 m diameter must be excavated. Vacuum, however is not required. As the beam is pointing down $\sim$ 35 mrad in order to cross the GRANDE detector at 400 km distance and approximately at sea level, no iron shielding is required. The muons will be absorbed after $\sim$ 600 m and the close detector (see Section 3) can therefore be located at $\sim$1 km distance. In total about 10^4 m^3 of earth have to be excavated from the surface and 10^3 m^2 should have a concrete floor and roof.

Some holes should be drilled into the earth shield for insertion of solid state detectors which will monitor the muon flux.

The performance of this beam line can be firmly predicted from experimental data, for instance from the wide band neutrino beam facility at CERN [7] operating at 450 GeV and from its proven Monte Carlo simulation [8]. The spectrum of events is shown in Figure 3. The mean event energy is $\bar{E}_\nu = 19.6$ GeV and the rates expected in the close and in the far detector are given in Table 1.

Detector	Mass	Distance	CC Events	NC Events
Close	30 t	1 km	8×10^6	2.4×10^6
Far	3×10^5 t	400 km	5×10^5	1.5×10^5

Table 1: Events in the close and in the far detector for 2×10^{19} protons on target.

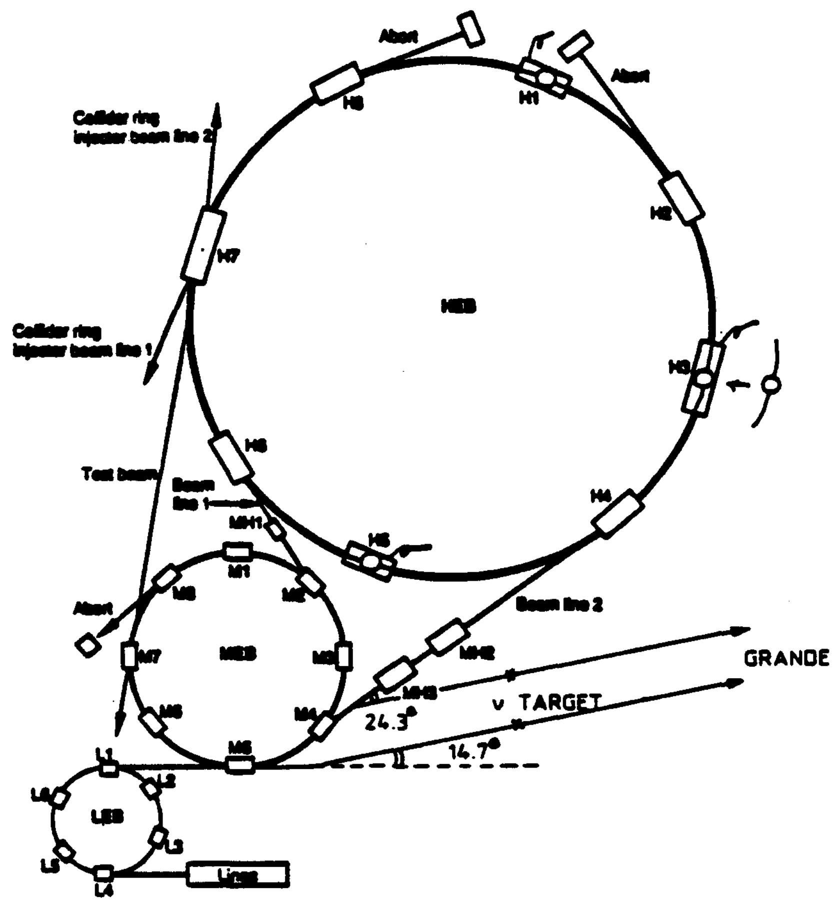

Figure 1: The Medium Energy Booster (MEB) of 200 GeV protons and the two possible beam lines towards GRANDE.

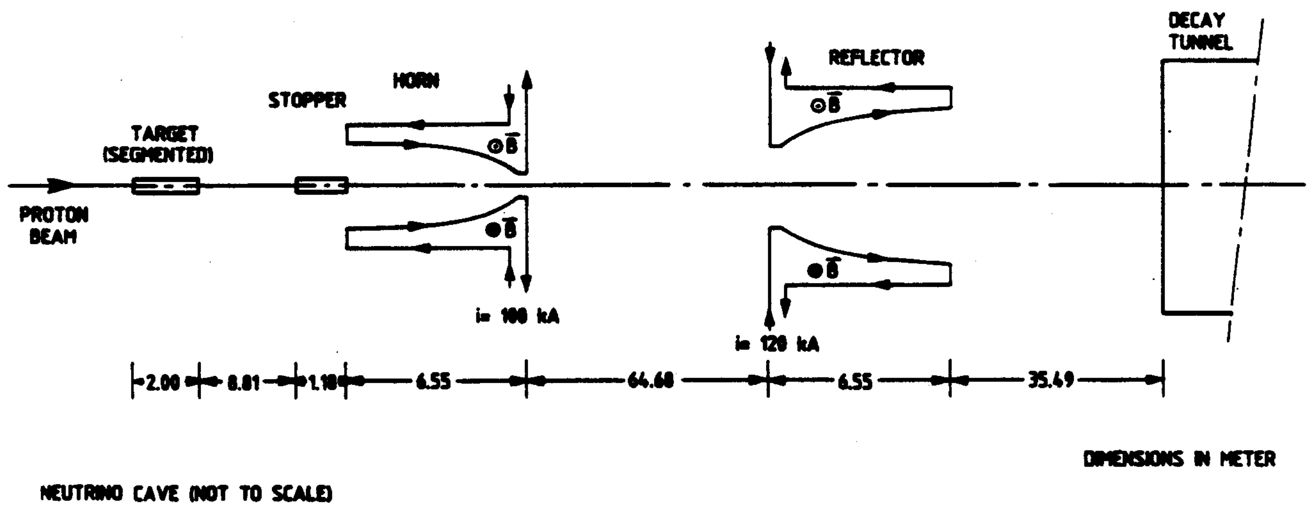

Figure 2: The neutrino beam line with the beryllium target, the horn, the reflector and the decay tunnel.

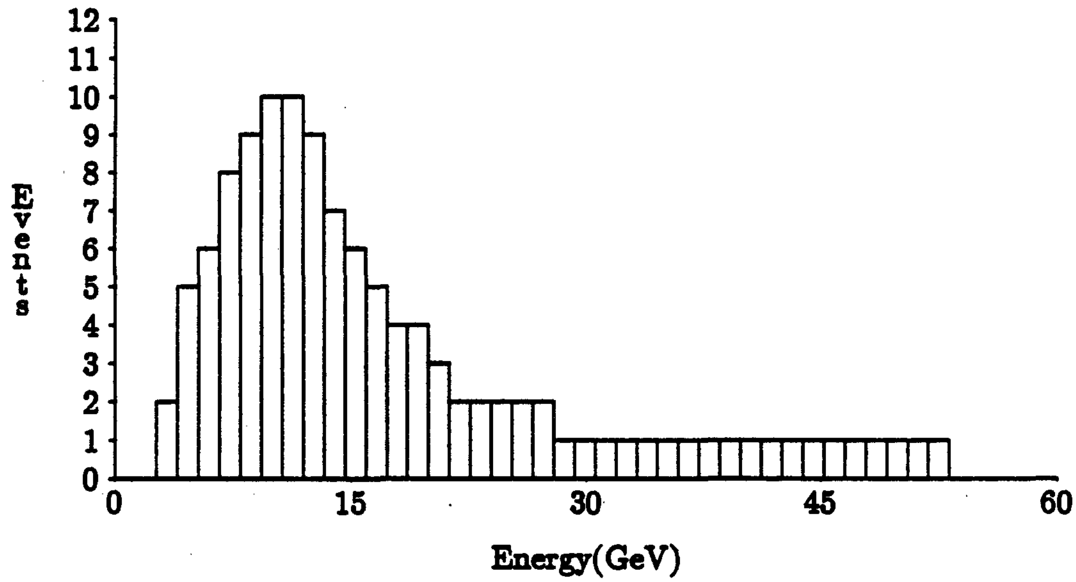

Figure 3: Neutrino event spectrum at GRANDE produced by 200 GeV protons on target. The mean event energy is 19.6 GeV.

3 The Detectors

To perform a long baseline neutrino oscillation experiment, one needs a very large detector at a long distance from the SSC. If too far away, however, the size of detector required for reasonable event rates becomes extremely large and costly. Only a water Čerenkov detector, such as GRANDE, is a cost effective solution to this dilemma. We believe that the GRANDE detector, to be located at 400 km from the SSC, is at an optimal distance and is of the correct size to perform such an experiment.

As previously discussed, we are studying various techniques for this experiment, and in Sect. 4 we describe two of them. One uses the GRANDE detector alone; the other uses GRANDE plus an additional detector close to the SSC. Since the techniques do not have conflicting hardware requirements, they could be used simultaneously.

Whether one uses either one or two detectors, cosmic ray induced backgrounds would be minimal or nonexistent. Only those events during the SSC spill time would be accepted; the requirement that events must point back to the SSC with high accuracy could also be made. Backgrounds should therefore not be a problem. In addition "beam-off" data would be accumulated to measure all non-neutrino backgrounds.

3.1 The "far" detector

The GRANDE facility has been designed to study many aspects of high energy particle-astrophysics. The detector is an imaging water Čerenkov device which evolved directly from the well understood IMB detector.

The facility is located in an unused quarry near Little Rock, Arkansas (34° 28' N, 92° 49' W), ~400 km from the site of the SSC.

The detector (Fig. 4) consists of a light-tight plastic membrane bag in the shape of a right circular cylinder, 200 m in diameter and 50 m deep, filled with purified water. The bag is suspended in the water-filled quarry by means of surface flotation; its position is stabilized by a system of cables to shore. Access ports in the top surface provide for installation of photomultiplier strings. The detector interior is divided horizontally into five optically isolated, ten meter thick regions by means of membrane shields connected to the PMT strings.

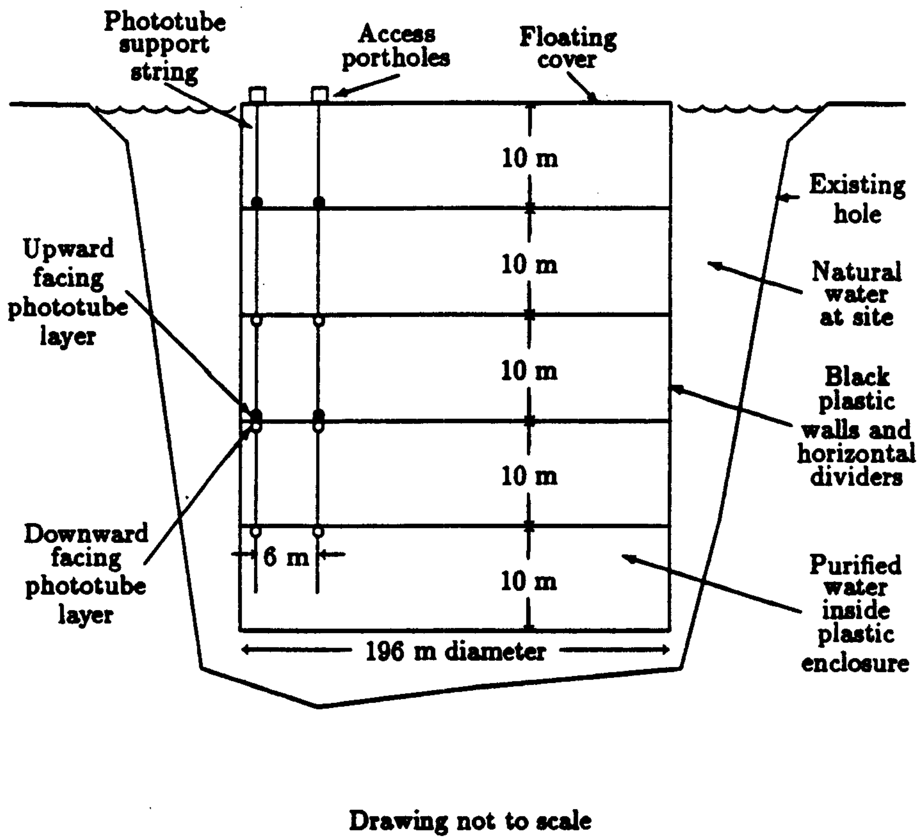

Figure 4: The GRANDE detector.

The two layers containing upward-looking PMTs are used as a γ-ray detector to observe extensive air showers and also can serve as an active cosmic-ray anticoincidence. The three lower layers contain downward-looking PMTs which are used as a neutrino telescope. A central layer is equipped with both upward- and downward-facing sensors and serves as the target and detector for the long-baseline neutrino oscillation experiment. It contains $\sim 3 \times 10^5$ metric tonnes of water, and is viewed by ~1600 PMTs (9 inch diameter) located on a 6 meter grid.

The IMB detector was the first of the large, imaging Čerenkov detectors. It has successfully operated for nearly a decade and is well understood. We have based much of our detector design on IMB and have used our expertise with that detector to aid in the development of the Monte Carlo codes for GRANDE. Monte Carlos and data from IMB have been extensively used and give us great confidence in our ability to predict the characteristics of GRANDE.

In operation, an imaging Čerenkov detector determines the location of the vertex and energy of an interaction, and the trajectory, energy, and particle type of the of the resultant particles. This information is deduced from the timing and number of photons detected by each PMT, and the pattern of the hit PMTs. As is shown elsewhere in this document, GRANDE is especially suited for distinguishing between short range showering particles such as electrons and similar energy longer range non-showering particles such as muons.

The current design of GRANDE, optimized for particle astrophysics with cosmic rays, will require no modification to act as the far detector in the proposed long baseline experiment. However, one of the detector's strengths is the extreme ease with which it can be modified in the face of changing experimental requirements. For example, the addition of ~800 PMTs in a second layer of water would more than double the detector's fiducial volume, and thus the rate of neutrino interactions per unit of beam time. Similarly the location and density of PMTs in any layer is easily changed, for example to more highly instrument a given region of the detector or to add veto regions.

A full description of the GRANDE detector and its operational characteristics can be found in reference [9]. As shown there, the schedule for construction is well matched to the time table of the SSC; the detector will

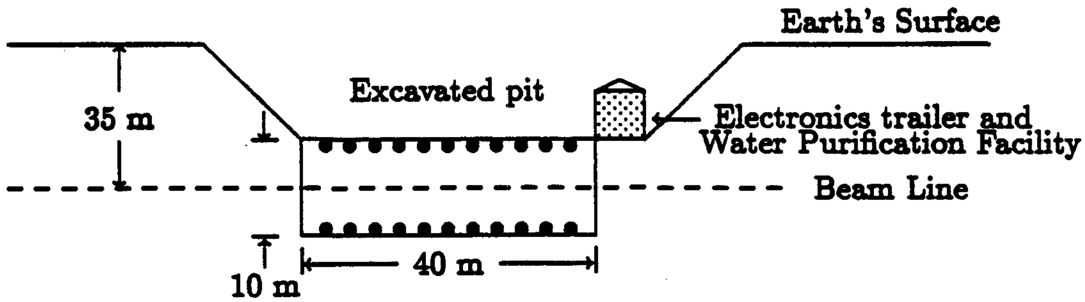

Figure 5: Sketch of the near-detector facility. The detector is a light-tight box filled with purified water. A plane of downward-facing PMTs is at its top; a plane of upward-facing at its bottom.

be operational within four to five years of the commencement of funding.

3.2 The "near" detector

The major purpose of the near detector is to determine the beam characteristics close to the target with the same systematics as those of the far detector. In particular, to determine the ratio of NC to CC events at that location. This detector will also permit a detailed study of neutrino interactions in water. This data will enhance our understanding of these processes, and permit a more robust analysis of the experimental data.

A sketch of the detector facility is shown in Fig. 5.

There are two competing factors to be considered when selecting the location for the near detector:

- The detector must be far enough away from the target to permit a sufficient number of pions to decay, i.e., to form a sufficiently intense neutrino beam, and for the muon flux to be absorbed.

- Since the distance to the far detector (GRANDE) is 400 km and the earth's surface is curved, the beam must point 35 mrad below the horizontal. Thus the further away the near detector is from the target, the deeper below the surface of the earth the detector must be placed.

A reasonable compromise between beam intensity and the excavation costs suggests that the detector be placed $\sim$ 1 km from the target. This corresponds to a beam line depth of 35 m at the detector.

The fiducial mass of the detector is determined by the distance from the target and the desired event rate. For an event rate of about 10 times that of the far detector (which has fiducial mass of 3×10^5 tonnes), the fiducial mass must be about 30 tonnes.

In order to insure that systematic effects in the two detectors are very similar, both detectors must be similar in design, except for size. Thus the geometry of the near detector must be matched to that of the far detector.

This means that the vertical height of the detector must be 10 m, the same as that part of GRANDE which is to be used. Preliminary analysis indicates that the width of the detector should be $\sim$40 meters. The length of the detector (along the beam direction) is given by the desired fiducial mass and the range of the muons to be detected. Since the beam diameter is 1 m, a fiducial mass of 30 tonnes requires a fiducial length of 30 meters; taking into account the muon range, the length of the detector must be 50 meters.

Because of the curvature of the earth, a hole will have to be dug to position the detector in the neutrino beam line. For a detector of dimensions 10 m high $\times$ 40 m wide $\times$ 50 m long with the beam line located 35 m below the earth's surface, we estimate a pit of 180,000 cu yds will have to be excavated.

The most likely cost-effective way to build the detector enclosure is to dig a pit of the desired dimensions and cover the sides and bottom with a standard geotextile material. The top surface of the detector would be a commercial water reservoir cover. This is a well-known technology.

The detector will have two horizontal planes of PMTs. All PMTs in the top plane will be downward facing; in the bottom, upward facing. The PMTs will be identical to those used in the far detector ($\sim$ 9").

In order to perform the more detailed analysis of the events required to understand the neutrino interactions in water, PMTs will be placed on a 3 m grid in both planes. This spacing also permits each event to be fit four times (on a 6 m by 6 m grid, identical to that of the far detector). These additional fits will be valuable in understanding certain classes of systematic errors.

The electronics will be identical to that used in the far detector. The counting house will be a trailer placed near the excavation.

In order to insure data comparable to that obtained in the far detector, the water must have comparable optical properties in both detectors. This will require that a small water purification facility be built near the detector. Its capacity will be ~8,000 gals/hr in order to turn over the entire volume in one month.

4 The Experimental Techniques

4.1 Event-length technique

Simulations show that horizontal particles passing through the sensitive layer of GRANDE produce an average of 15 ± 2 photoelectrons per GeV of deposited energy. The energies of muons that range out in the detector can thus be determined with statistical accuracy of $\delta E/E \approx 0.26/\sqrt{E(GeV)}$. For electrons and π^0's showering processes lead to larger statistical fluctuations.

Particle ranges provide a means for particle identification. Muons lose energy at a constant rate of ~2 MeV/cm. Many of the muons with E < 40 GeV will therefore range out in the detector. With a radiation length in water of 36 cm, most of the electromagnetic showers will range out and produce a pattern of PMT hits distinctly different from that for muons. This is illustrated in Figs. 6 and 7 where the numbers of PMTs hit and photoelectrons collected are plotted as a function of the distance from the vertex of the light-emitting track segments. Distributions for both electrons and muons of 20 GeV are shown.

Hadronic cascades produced by charged pions will also be significantly shorter than muons of corresponding energies. Therefore, the production of muons with $E_\mu > 5$ GeV via the charged-current interactions of ν_μ's can be selected with good efficiency.

By comparing the values of R in both the near and far detectors, one can perform a very sensitive search for neutrino oscillations.

Further studies of energy as well as vertex and angular resolutions are underway. Simple enhancements of this layer such as adding layers of PMTs facing the direction of the SSC or providing a volume array of PMTs inside GRANDE are also being studied.

4.2 Using energy distributions to detect neutrino oscillations

This technique uses only the far detector. Due to GRANDE's large size, it is a very effective calorimeter. Thus it is possible to measure the the ratio R as a function of energy. If ν_μ's oscillate into ν_τ's, one would expect that

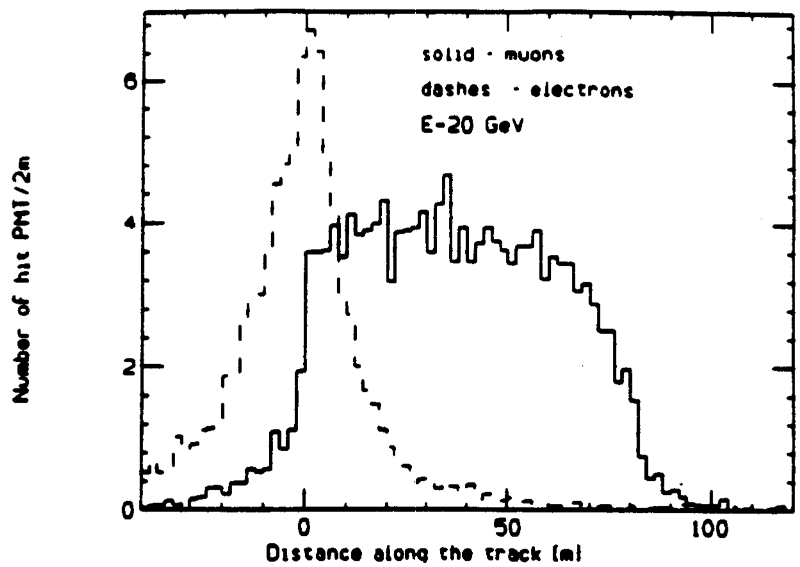

Figure 6: The numbers of photomultiplier tubes illuminated along the track of a 20 GeV muon and a 20 GeV electron.

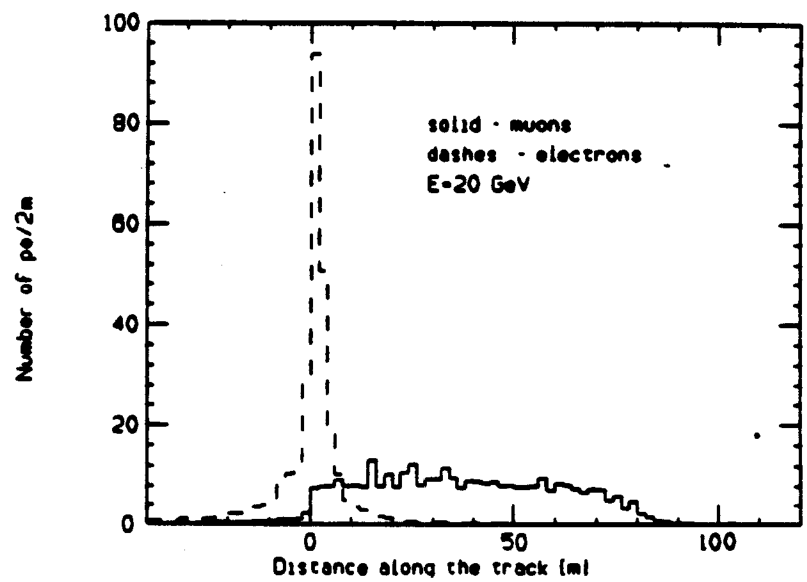

Figure 7: The numbers of photoelectrons collected along the track of a 20 GeV muon and a 20 GeV electron.

the energy dependence of R would be significantly altered. Our preliminary studies of this technique indicate that we may attain a statistical sensitivity (90% c.l.) of $|U_{\mu\tau}|^2 < 7 \times 10^{-3}$ for $\Delta m^2 > 0.06\ eV^2$. The systematic effects are being studied.

5 Budget

The three major components of the budget are:

- The beam line
- The far detector (GRANDE)
- The near detector.

5.1 The beam line

The costs for the beam line are based on the actual costs at CERN.

Fast-slow ejection system from MEB	500,000	
Proton beam line to target, power supplies, cables, cooling, vacuum	500,000	
Target and beam observation equipment	250,000	
Horn and reflector, supports, strip line pulsed power supply 100 KA, transformer, cooling	650,000	
Solid state detector hodoscopes, electronics for muon flux monitoring	120,000	
Excavation and enclosure	50,000	
Total		**$2,070,000**

5.2 The far detector

We anticipate no significant modifications or additions to the GRANDE detector for this experiment.

5.3 The near detector

These costs are based on the similar estimates in the GRANDE proposal [9].

Excavation

180,000 cu yds @ $2.00 — **360,000**

Detector enclosure

Materials and construction (60,000 ft^2@ $2)		**120,000**
PMTs		
Tubes (200), bases, plus spares		**155,000**
Electronics		
PMT Interface	15,700	
High Voltage	10,500	
Custom Crate Electronics	15,000	
Trigger Processor	13,500	
Digitizer	24,000	
Event Builder	80,370	
Command & control	60,000	
Monitoring/on-line analysis	14,600	
Electronics subtotal		**233,670**
Calibration System		**27,000**
Water System		
Site preparation	10,000	
Water system components	200,000	
subtotal		**210,000**
Site Engineering and Studies		
Environmental assessment, analysis, and permits	5,000	
General site engineering	5,000	
subtotal		**10,000**
Buildings		
Central Data Acquisition House (800 ft^2)	16,320	
Air conditioning	6,000	
subtotal		**22,320**
TOTAL Construction Budget		**$ 1,137,990**

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A Very-Long Baseline Neutrino Oscillations Experiment at the SSC
EOI-004

Todd Haines
University of Maryland

SSC PAC Meeting
June 7, 1990.

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GOAL: Perform $\nu_\mu \rightarrow \nu_x$

- $\Delta m^2 > 0.07 eV^2$
- $sin^2 2\theta > 10^{-2} \rightarrow 10^{-3}$ stat.

- Motivation for New Long Baseline Neutrino Oscillations Experiment
  - Theoretical
  - Experimental
- The **G**amma**R**ay**A**nd**N**eutrino**DE**tector
- The SSC $\leftrightarrow$ GRANDE Connection
  - The Neutrino Beam
  - The Near Detector
  - Experimental Technique
  - Capabilities
- Short-Term Goals
- Costs and Requirements
- Summary

CKM Mixing Matrix

Use CKM matrix as a guide to neutrino mixing parameters

	d	s	b
u	0.975	0.222	0.004
c	0.222	0.974	0.044
t	0.009	0.043	0.999

$$\nu_e \to \nu_\mu \overset{?}{\simeq} |V_{12}|^2 \simeq 5 \cdot 10^{-2}$$

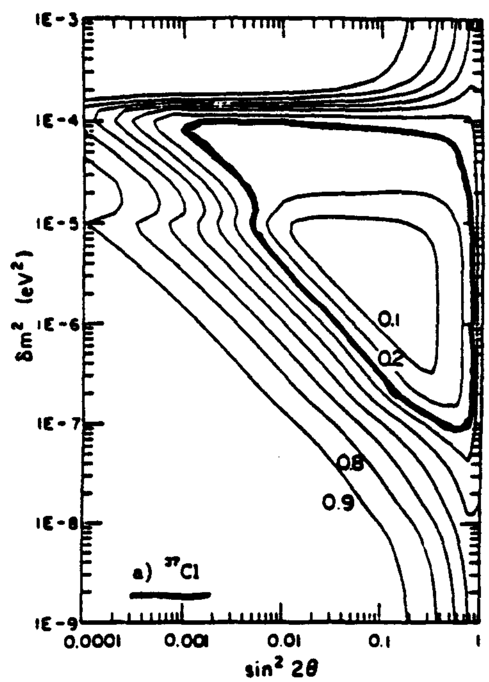
$$\nu_e \to \nu_\tau \overset{?}{\simeq} |V_{13}|^2 \simeq 4 \cdot 10^{-5}$$

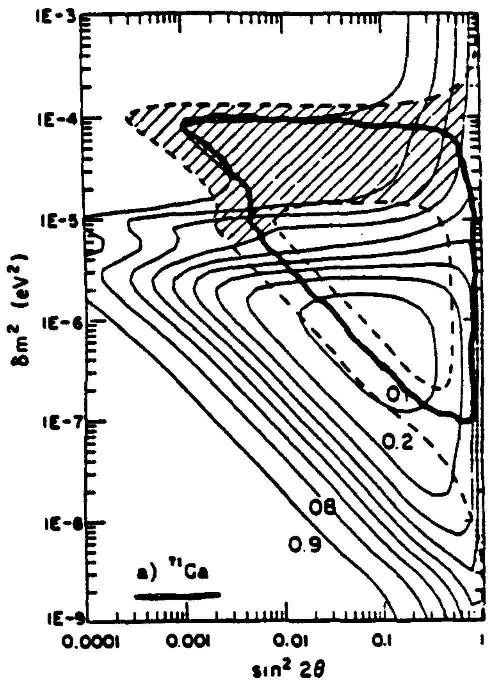
$$\nu_\mu \to \nu_\tau \overset{?}{\simeq} |V_{23}|^2 \simeq 2 \cdot 10^{-3}$$

2 component model $\sin^2 2\theta = |V_{12}|^2 \sim 10^{-2} - 10^{-3}$

Solar Neutrino Puzzle

Suppose solar "deficit" due to MSW mechanism:





Then $\Delta m^2{}_{e\mu} \approx 10^{-4} eV^2 \Rightarrow m_{\nu_\mu} \approx 10^{-2} eV$

"See-Saw" Mechanism $\mathrm{m}_{\nu_e}:\mathrm{m}_{\nu_\mu}:\mathrm{m}_{\nu_\tau} \propto \mathrm{m}_e^n:\mathrm{m}_\mu^n:\mathrm{m}_\tau^n$

$\rightarrow \mathrm{m}_{\nu_\tau} \sim$ **0.17 eV - 3 eV**

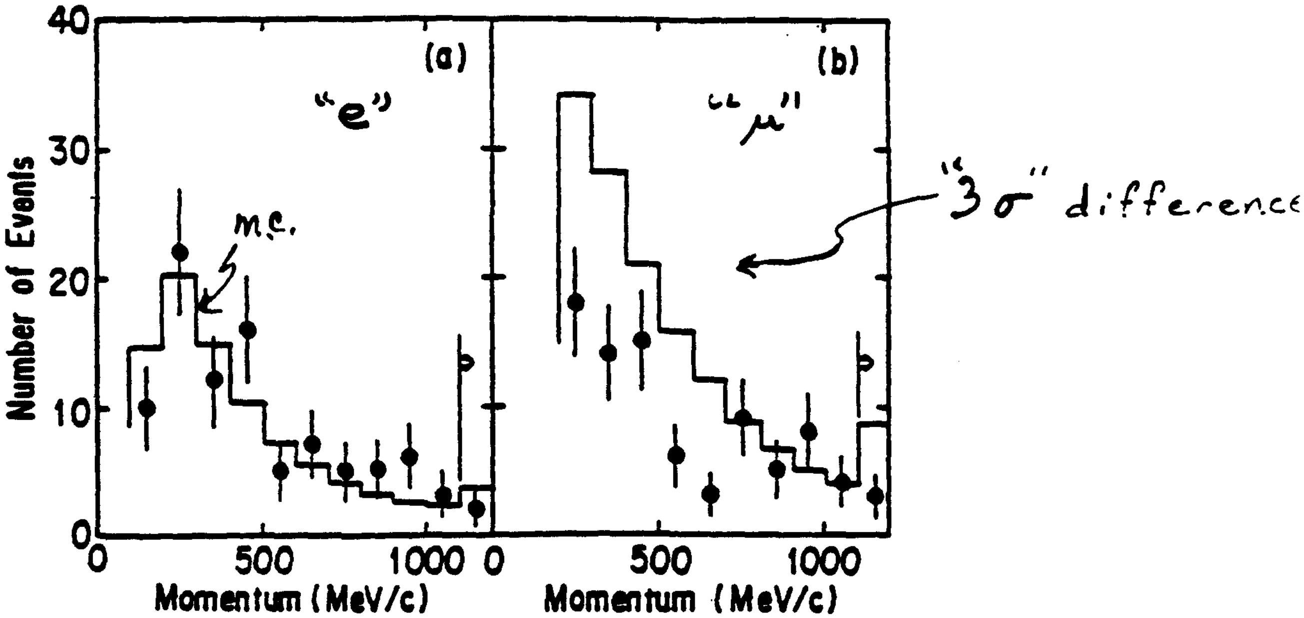
Thus $\underline{\Delta m^2{}_{\mu\tau} \approx 0.03 eV^2 \text{ — } 10 eV^2} \Leftarrow$ Unexplored!

Some ν_μ oscillation experiments

Experiment	Type	"$\overline{E}$" GeV	Approx. L km	L/E km/GeV
BNL E734	$\nu_\mu \rightarrow \nu_e$	1	0.1	0.1
BNL E776	$\nu_\mu \rightarrow \nu_e$	1.3	1	0.8
BNL E816	$\nu_\mu \rightarrow \nu_e$	1.5	0.13	0.09
BEBC	$\nu_\mu \rightarrow \nu_e$	1.5	0.82	0.6
CHARM	$\nu_\mu \rightarrow \nu_e$	1	0.9	0.9
LAMPF E645	$\nu_\mu \rightarrow \nu_e$	0.03	0.026	0.9
SKAT	–	5	0.27	0.5
FNAL E531	$\nu_e,\nu_\mu \rightarrow \nu_\tau$	–	–	0.01-0.02
SSC-GRANDE	$\nu_\mu \rightarrow \nu_e,\nu_\tau$	20	400	20

Clear need for experiments to explore the regime of L/E $\gg$ 1 km/GeV.

Kamiokande-II Result



$$\Delta m^2_{\mu\tau} > 0.03 \text{ eV}^2 \text{ and } \sin^2 2\theta \simeq 1$$

or

$$\Delta m^2_{e\mu} > 0.03 \text{ eV}^2 \text{ and } \sin^2 2\theta \simeq 0.80$$

How to Detect Neutrino Oscillations

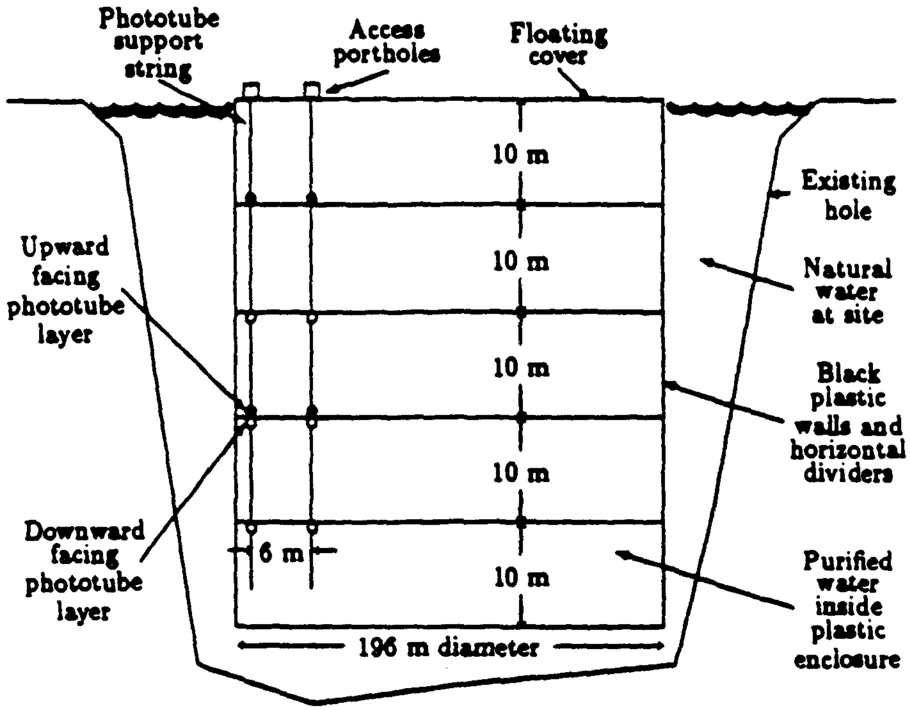
$$R = \frac{N(NC)}{N(CC)}$$

"NC" – Muon-less Event
"CC" – Event with Muon

- $\nu_\mu \rightarrow \nu_\tau$
  83% of τ decays are muonless
  $\Rightarrow$ N(NC) increases, N(CC) decreases $\Rightarrow$ R ~~de~~in-creases

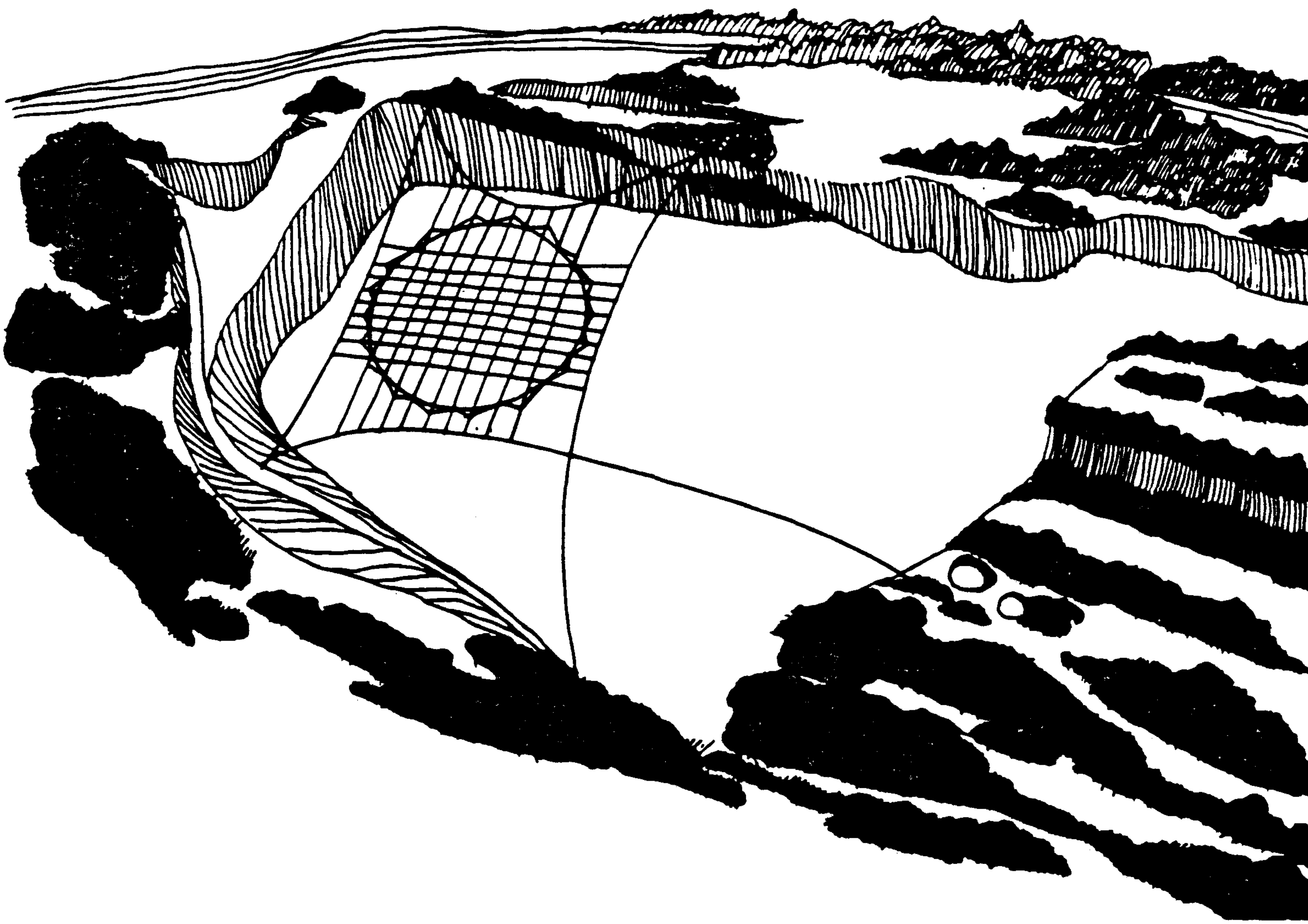
- Energy deposited in "real" ν_μ NC $\ll$ that in ν_τ CC
  $\Rightarrow$ R(E_{vis}) is more sensitive to oscillations

GammaRayAndNeutrinoDEtector



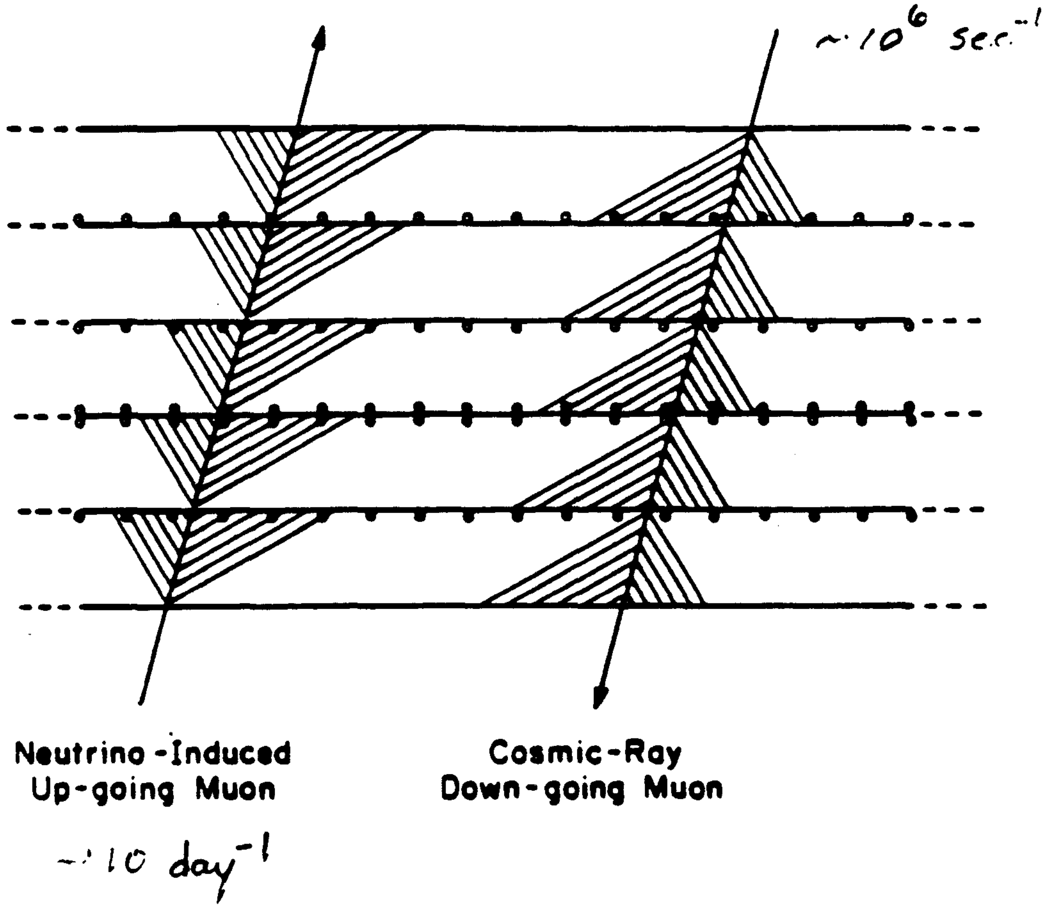
Drawing not to scale

- Size – 200 m dia. × 50 m high 31,000 m^2 area
- Location – Abandoned mine near Little Rock, Arkansas
- PMTs – 3,940 9" on 6 m grid



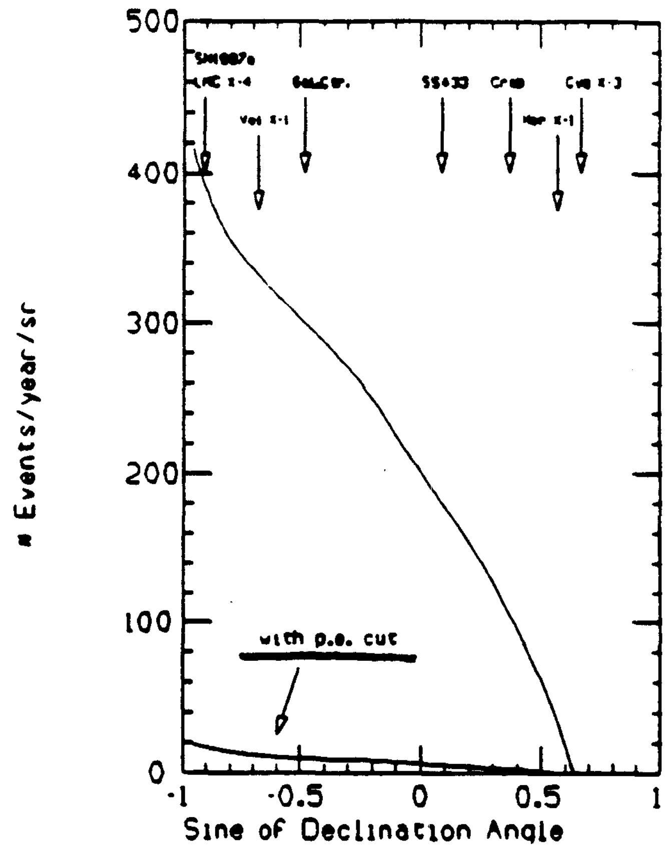
Artists conception of GRANDE at Arkansas site
(Aerial View)

How GRANDE Detects Astrophysical Neutrinos



- Angular Resolution < 1°
- 80 times larger than existing detectors
- 2,500 atmospheric neutrinos per year
- 10's of neutrinos from astrophysical sources per year

Atmospheric Neutrino Background



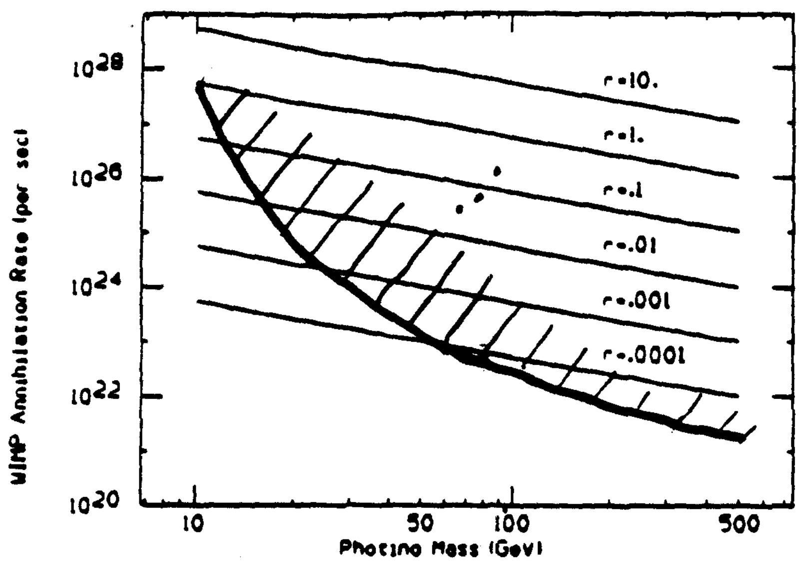
"Off-line" variable threshold unique to GRANDE.

$\frac{dE}{dx}^{\mu}$ ↑ for $E_\mu \gtrsim 1$ TeV

"pe cut" Tags high $\frac{dE}{dx}$ μ's

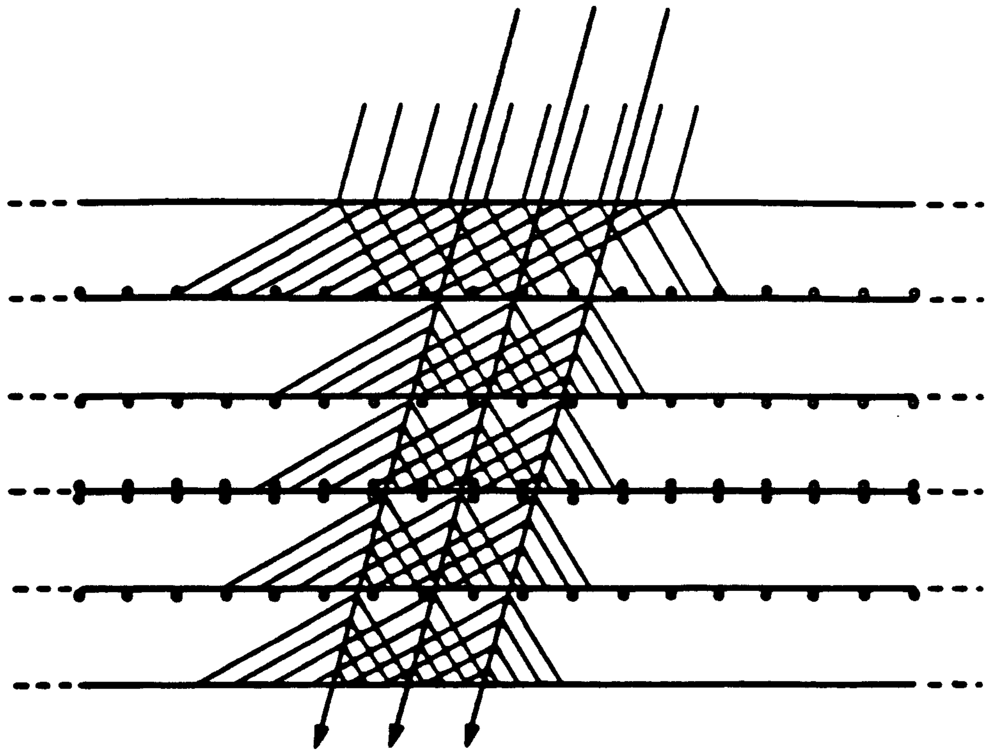
Dark Matter Detection

- Cold Dark Matter particles (WIMPs, χ) captured by the sun.
- $\chi\bar{\chi} \to f\bar{f} \to \nu$'s.
- Example: Suppose χ is photino, the LSP.



GRANDE will detect WIMPs with mass > 10 GeV.

How GRANDE Detects Air Showers



100% Coverage for:

$e^{\pm}$'s

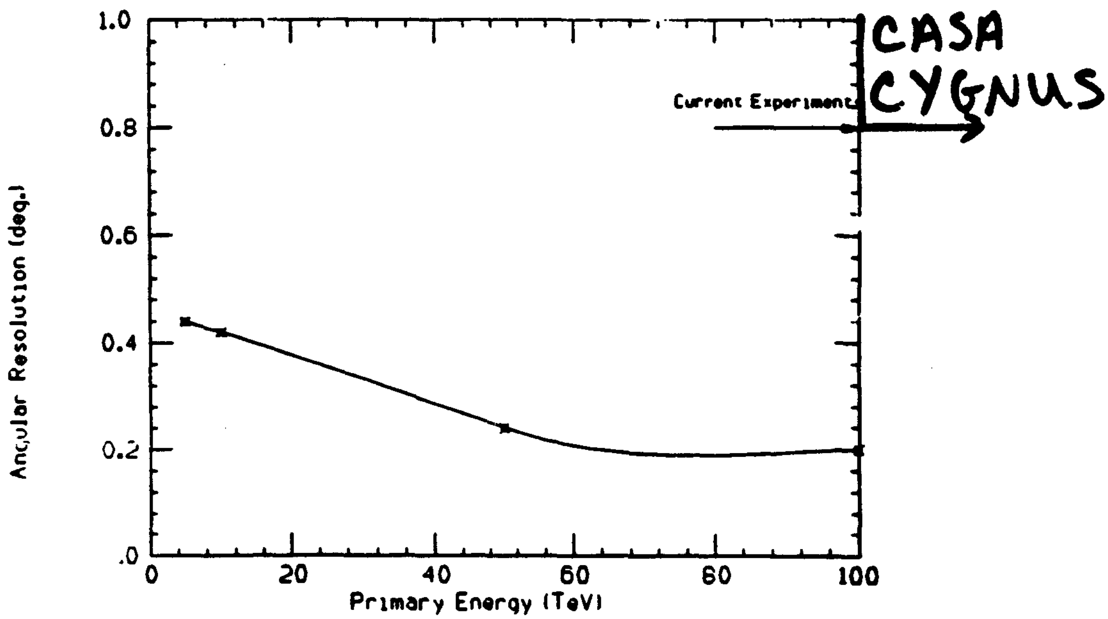
γ's

$\mu^{\pm}$'s

hadrons

⇒ very low ~ TeV Threshold Even at Sea Level!

Angular Resolution of GRANDE

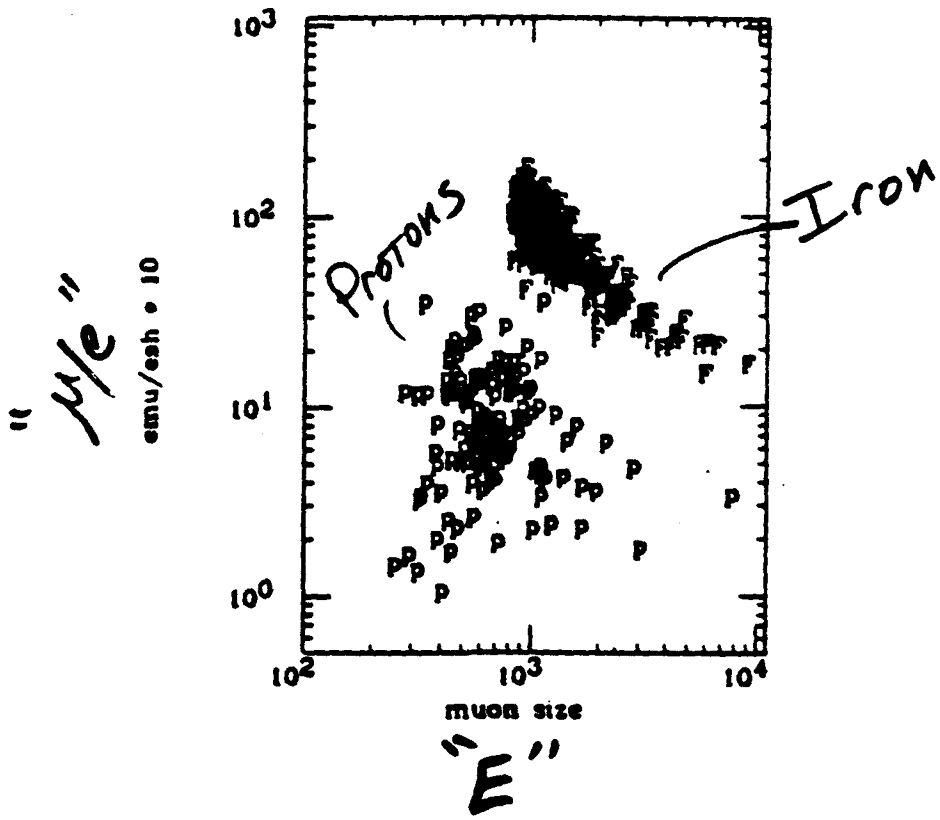


$\delta\theta = 0.2°$ at E > 10 TeV
$\delta\theta = 0.5°$ at threshold

Since S/N $\propto 1/(\delta\theta)^2$

~ 9 Times Better Than Existing Detectors!

Cosmic Ray Composition

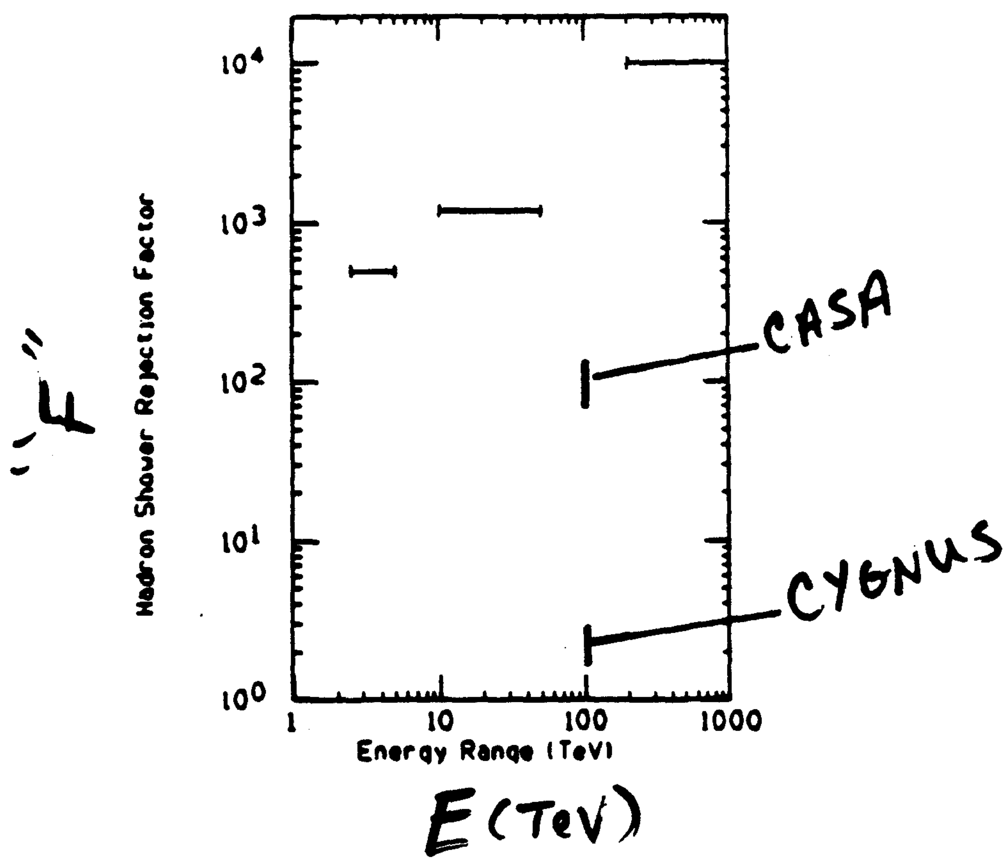


Composition provides important information on CR origin and propagation.

- GRANDE has Superior N_μ Determination
- GRANDE can Perform P/Fe Separation Event-by-Event
- GRANDE can Study Tagged Heavy N-N Collisions at $\sqrt{s} \sim 1$ TeV

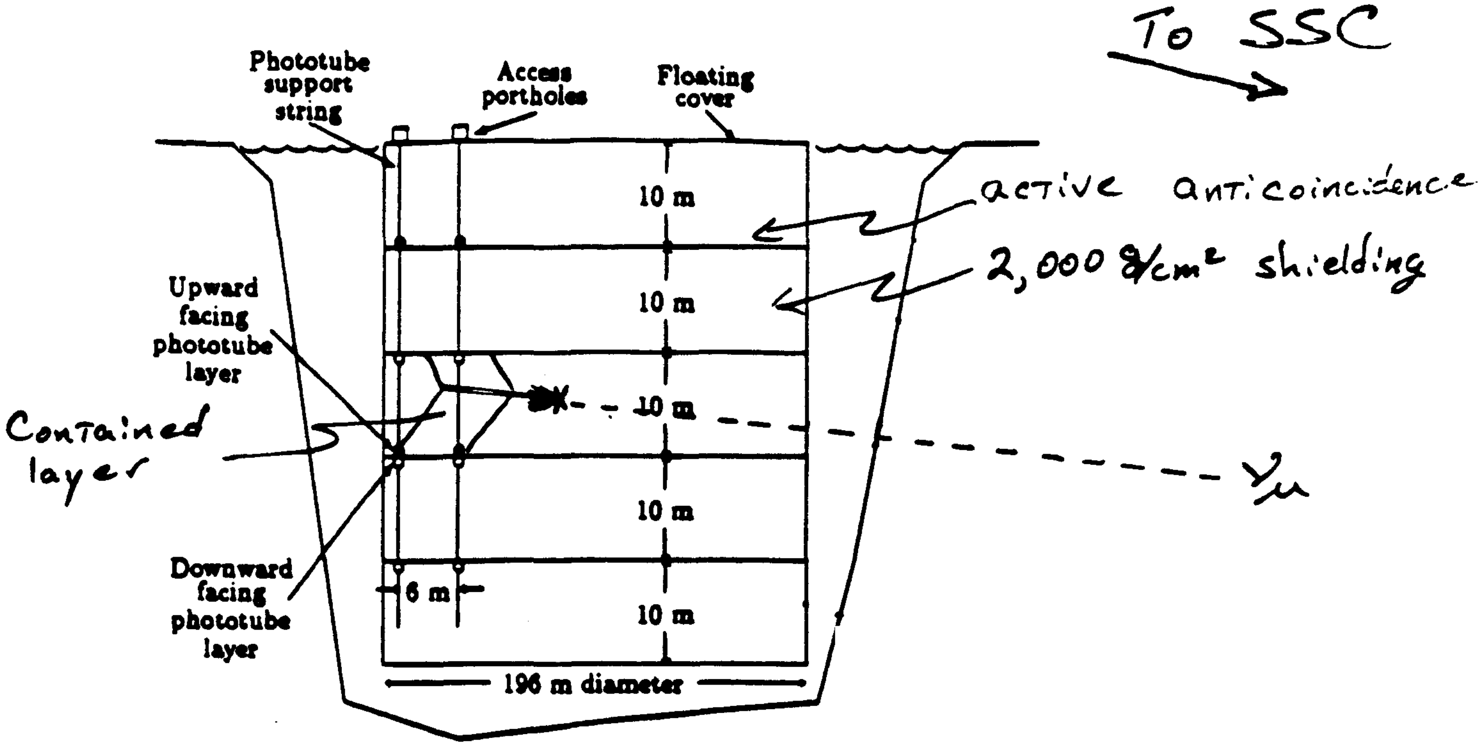
Muons and Background Rejection

$$N_\mu^\gamma \simeq \frac{1}{30} N_\mu^p$$



Reject Factor "F" of Background $\Rightarrow$ S/N $\propto \frac{F}{\delta\theta^2}$

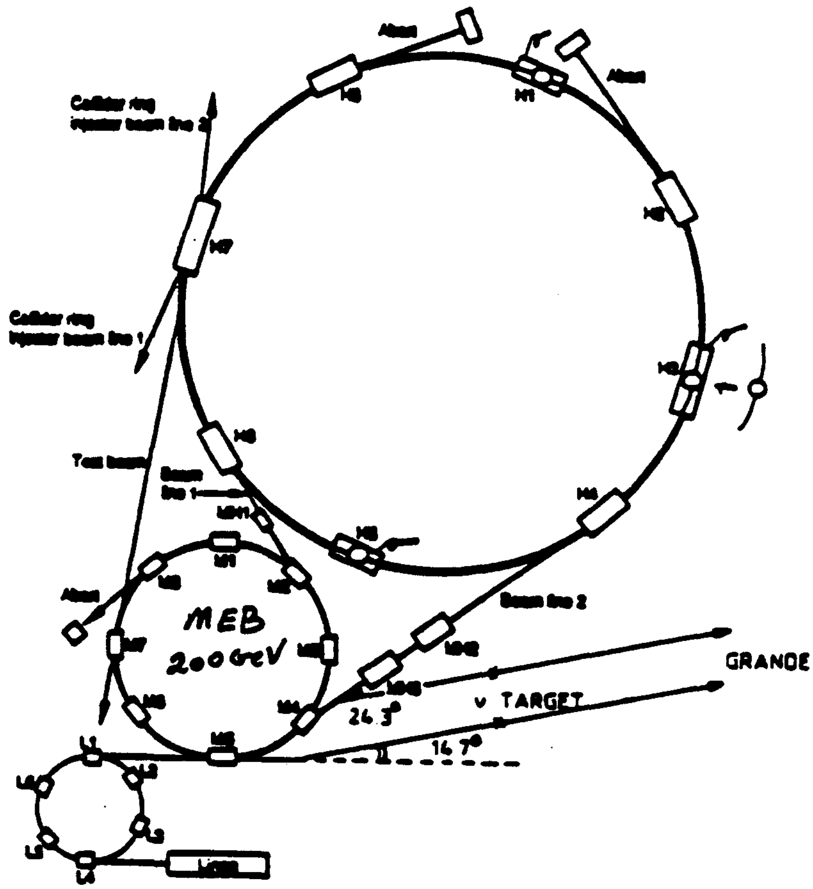
How GRANDE Detects SSC Neutrinos



Drawing not to scale

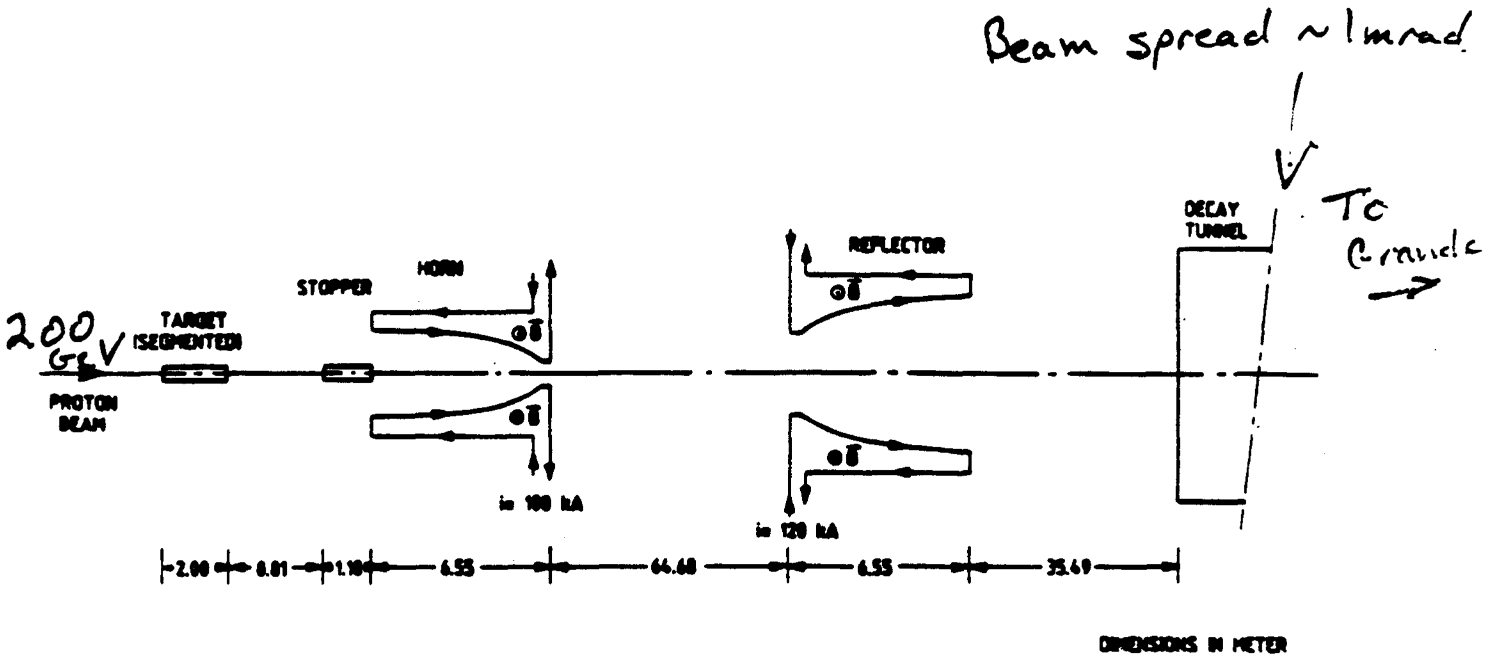
- Contained Layer Mass = 1/3 Mtonne
- Contained Layer Shielding 2,000 g/cm^2
- 1,576 PMTs Viewing Contained Layer

The Neutrino Beam



Need $\approx 2 \times 10^{19}$ POT
100% for 25 days
only 25% for 100 days

Decay region 300 m long × 1 m dia., 35 mrad down.



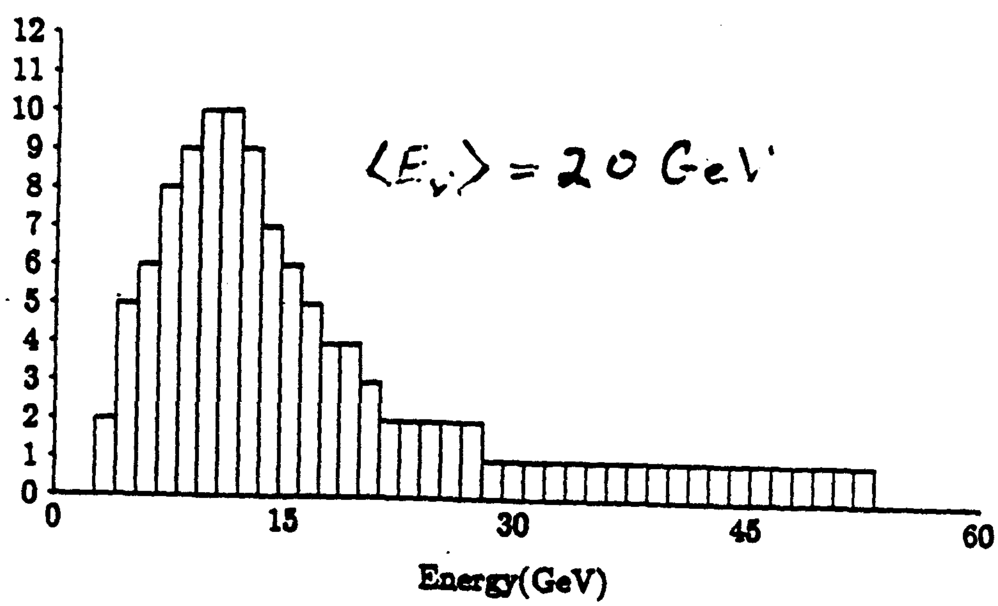
NEUTRINO CAVE (NOT TO SCALE)

1 mrad ⟹ 0.3 m @ 2nd of Tunnel

1 m @ "near" detector

4cc m @ Grande

Neutrino Spectrum and Rates



@ 25%

Detector	Mass	Distance	CC Events	NC Events
Close	30 t	1 km	8×10^6	2.4×10^6
Far	3×10^5 t	400 km	5×10^5	1.5×10^5

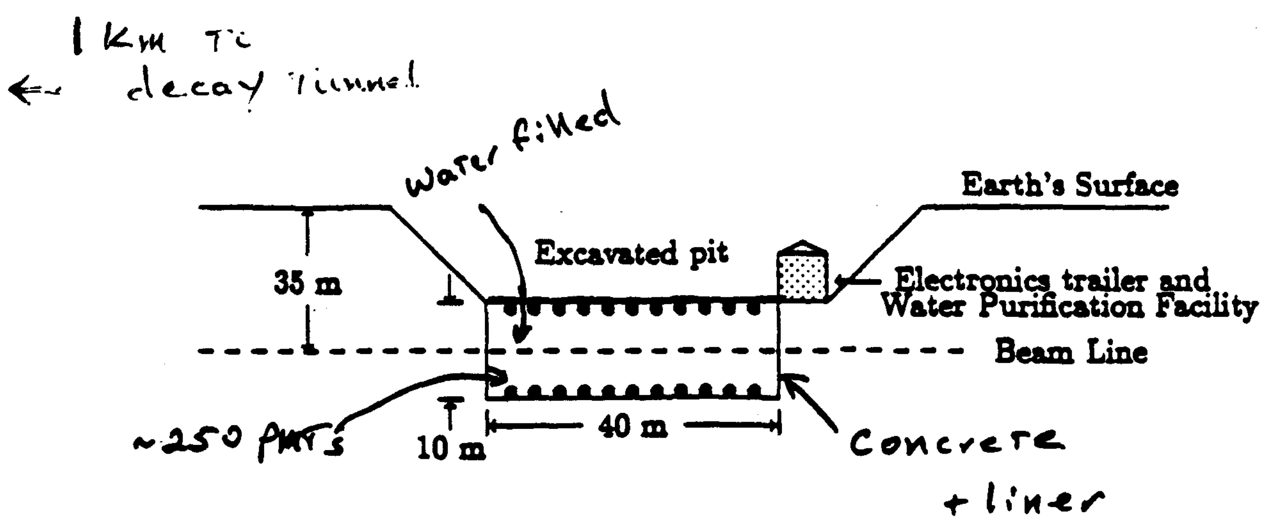
1.2 sec^{-1}
1/13 sec^{-1}

Events in the close and in the far detector for 2×10^{19} protons on target.

The Near Detector

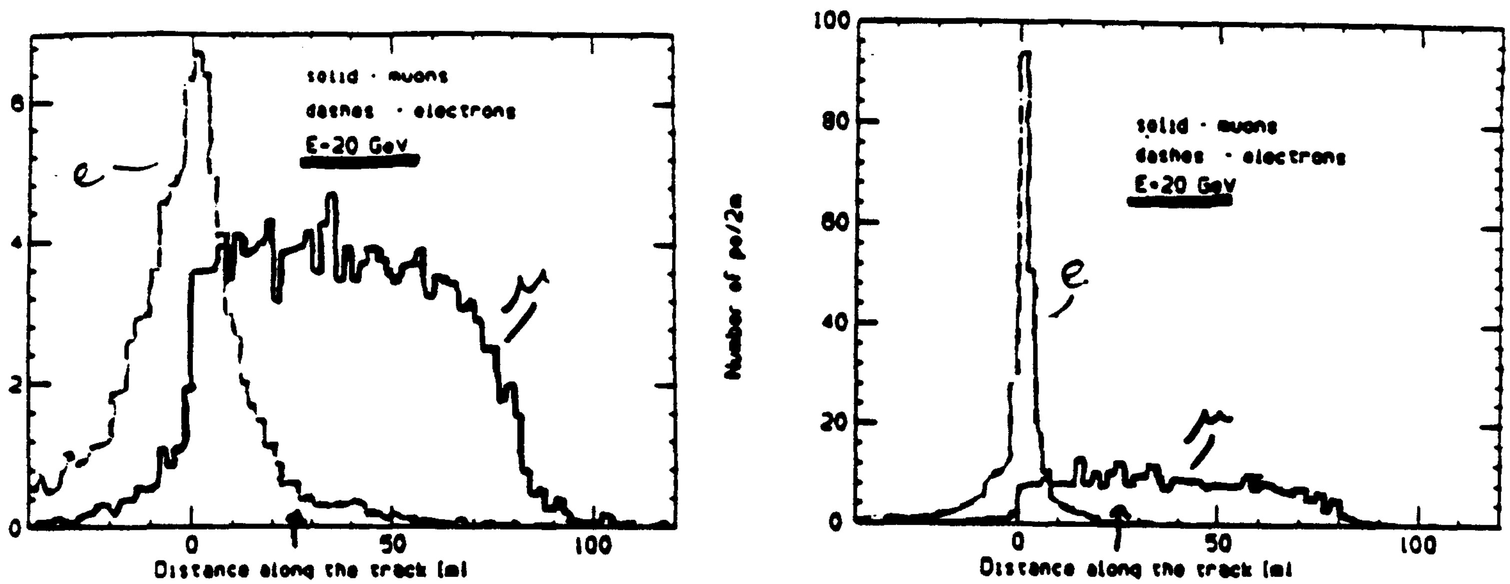
Purpose: Measure beam (esp. N(NC)/N(CC)) with same systematics as GRANDE.

- Distance from target – 1 km
  - Far enough away for sufficient intensity
  - Far enough away for muons to be absorbed
  - Since beam pointed down 35 mrad, close enough to be not too deep
- Rate 10$\times$ GRANDE $\Rightarrow$ Fiducial Mass 30 tonne
- Beam size – 1 m
- Geometric configuration – same as GRANDE
  - height – 10 m
  - width – 40 m
  - length – 50 m $\leftarrow$ enough mass and range
  - PMTs – identical except on 3 m grid $\leftarrow$ help with systematics


1 km to
decay tunnel
water filled
Earth's Surface
Excavated pit
35 m
Electronics trailer and
Water Purification Facility
Beam Line
~250 PMTs
10 m
40 m
Concrete
+ liner

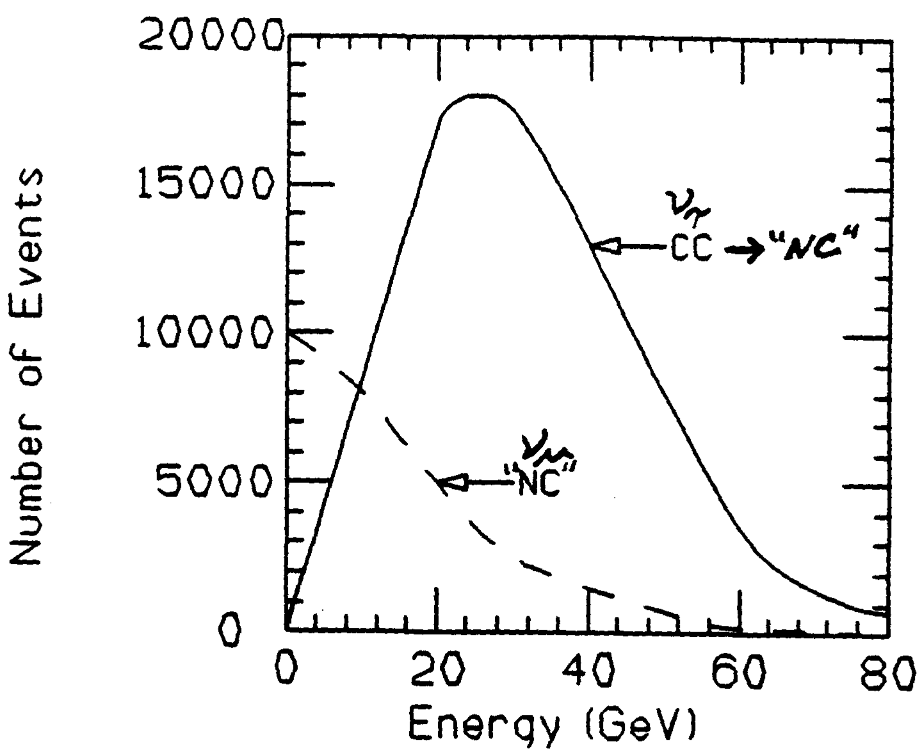
Experimental Technique

- Muon 2 MeV/cm yields 15 pe/m deposited ⇒ $\delta E/E = 26\%/\sqrt{E(GeV)}$
- $\lambda_{rad} = 36$ cm, $\lambda_{int} = 85$ cm

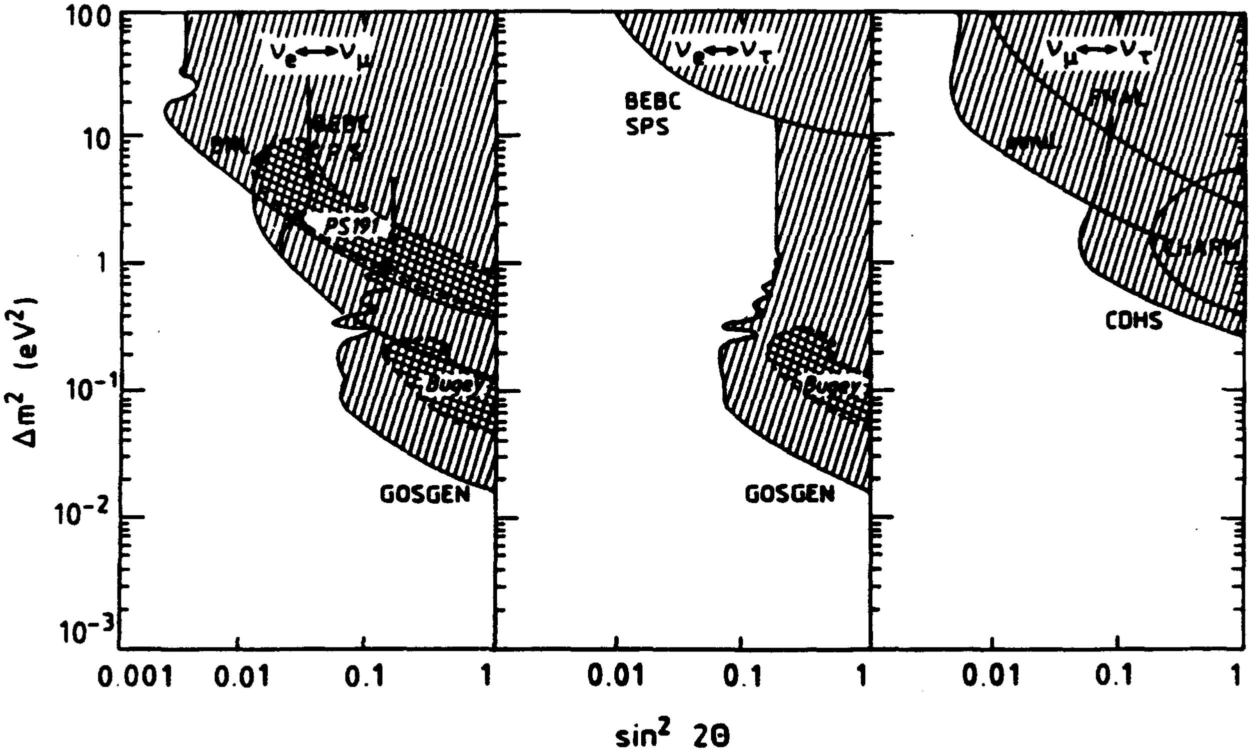


Using the "event length" one can identify events with $E_\mu > 5$ GeV as "CC".

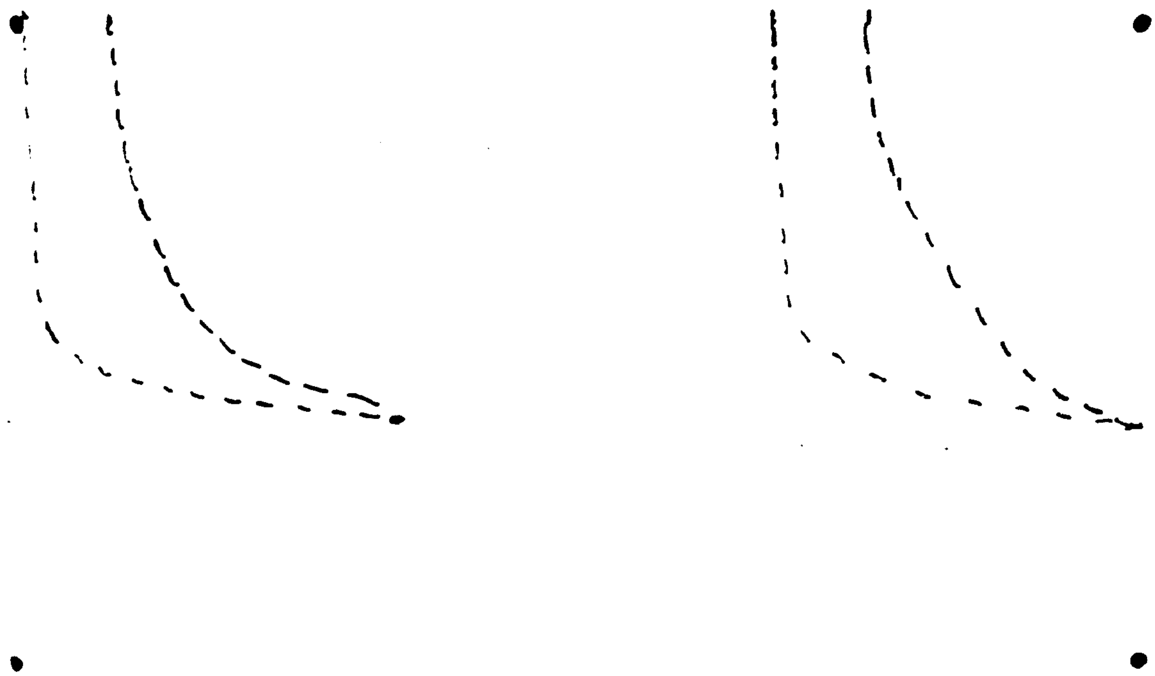
- ν_μ NC has much less visible energy than ν_μ CC
- Neutrino in NC event takes away much energy
- "NC" event sample is composed of:
  - Real ν_μ NC events
  - Apparent "NC" (muonless) events from $\nu_\mu \rightarrow \nu_\tau$ oscillation
- Since GRANDE is a large calorimeter, this will be observable in "NC" energy spectrum



Examination of R(E) will be sensitive indicator of oscillations.



$\nu_e \leftrightarrow \nu_\mu$
$\nu_e \leftrightarrow \nu_\tau$
$\nu_\mu \leftrightarrow \nu_\tau$
BEBC
SPS
PS191
Bugey
GOSGEN
CDHS
CHARM
FNAL
100
10
1
10^{-1}
10^{-2}
10^{-3}
Δm^2 (eV^2)
0.001
0.01
0.1
1
$\sin^2 2\Theta$

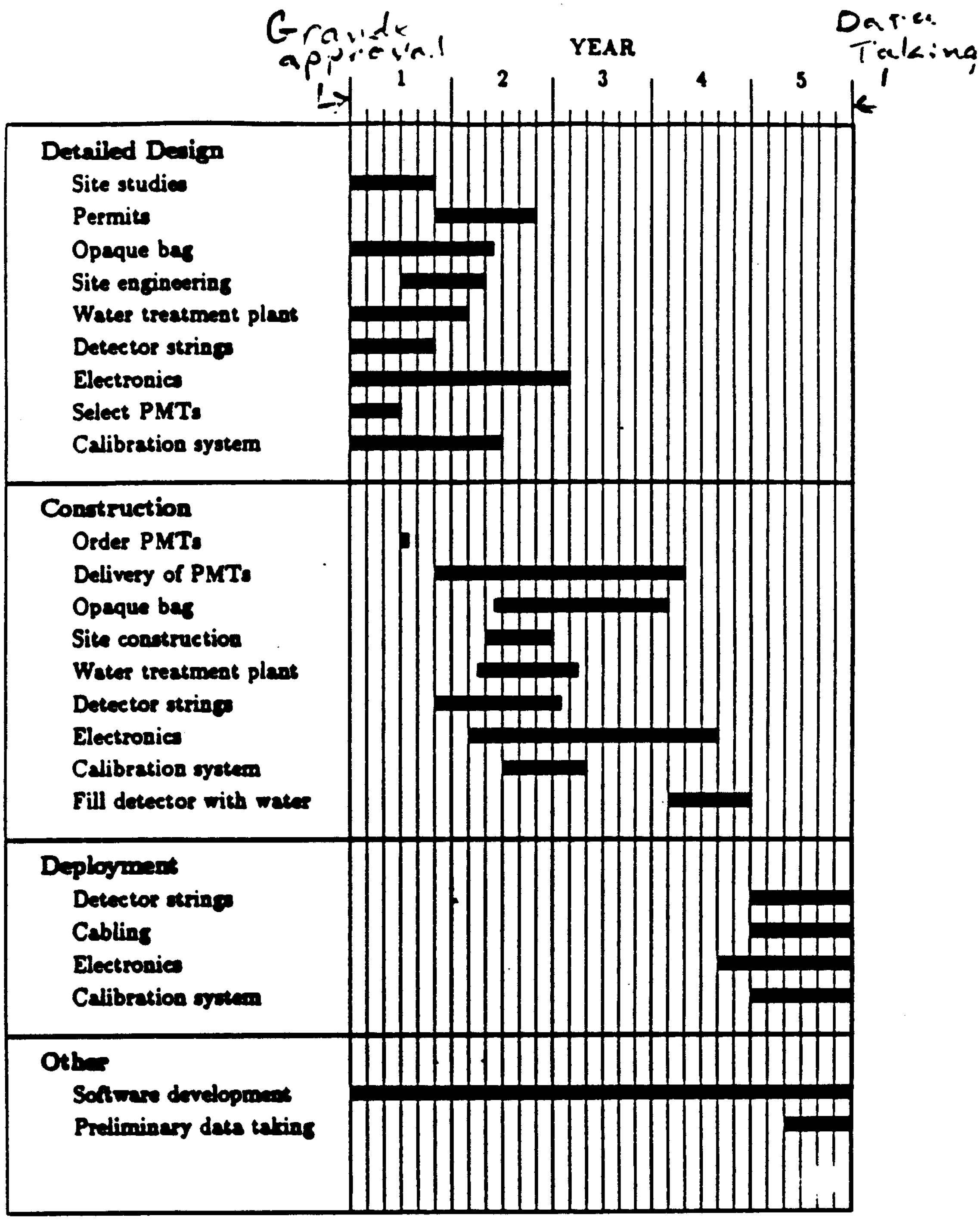


---- statistics 90% C.L. limit 2 detector R

---- " " Grande only R(E)

Short-Term Goals

- Evaluate beam characteristics and requirements
  - High-flux WBB vs. Low-flux NBB
- Evaluate detector resolutions
  - vertex and direction resolution
  - energy resolution
  - NC-CC classification and misidentification
- Evaluate systematics
  - Spectrum as fcn. of position
  - Efficiency as fcn. of energy
- Evaluate possible detector enhancements
  - Planes of PMTs facing SSC
  - Volume array of PMTs
  - More contained layers
- Enhance the collaboration



Grande Proposal under DoE review
decision by end of 1996.

Preliminary Cost Estimate

	Component	Cost ($)
The Beam Line	MEB to Target	1,000,000
	Target and monitoring	250,000
	Focusing	650,000
	Decay tunnel	50,000
Beam Line Subtotal		2,070,000
The Near Detector	Excavation	416,000
	Site	32,000
	Enclosure	120,000
	PMTs and Electronics	389,000
	Water system	210,000
Near Detector Subtotal		1,138,000
Total Cost		**3,208,000**

Minor changes to Grande ⇒ [illegible]

Summary

- The well-established water-Čerenkov technique represents a cost-effective method for large neutrino detectors.
- GRANDE represents the next major step in astrophysical neutrino detection.
- GRANDE is truly a "next generation" astrophysical gamma-ray detector.
- The GRANDE Proposal is currently under review by DoE.

Given the proper encouragement we will:
Expand the collaboration
Continue studies

to capitalize on the unique opportunity to perform an important neutrino oscillation experiment with the SSC-GRANDE collaboration.