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INSTITUTE FOR HIGH ENERGY PHYSICS

IHEP 95-18

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PHYSICAL AND TECHNICAL ASPECTS OF A NEUTRINO BEAM CREATING FROM UNK-1 AT THE ENERGY 600 GeV FOR LONG-BASELINE NEUTRINO OSCILLATIONS EXPERIMENTS

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Protvino 1995

UDK 539.12 M–24

Abstract

Bulgakov M.K. et al. Physical and Technical Aspects of a Neutrino Beam Creating from UNK-I at the Energy 600 GeV for Long-Baseline Neutrino Oscillations Experiments: IHEP Preprint 95-18. – Protvino, 1995. – p. 33, figs. 15, tables 9, refs.: 22.

The paper gives the preliminary consideration of a possibility to form beams from the 600 GeV UNK-I machine towards the Gran Sasso laboratory (Italy) as well as to study neutrino oscillations by using the ICARUS facilities. The expected range of studying the oscillation parameters depending on the experimental conditions is about Δm^2 up to 10^{-3} eV^2 at the complete mixing and $sin^2 2\theta$ up to $6 \cdot 10^{-3}$ at $\Delta m^2 \sim 2 \cdot 10^{-2}$ eV^2.

Аннотация

Булгаков М.К. и др. Физические и технические вопросы создания нейтринного пучка на длинные расстояния от ускорителя УНК-1 на энергию 600 ГэВ : Препринт ИФВЭ 95-18. – Протвино, 1995. – 33 с., 15 рис., 9 табл., библиогр.: 22.

В работе изложены результаты исследований возможности формирования нейтринных пучков от ускорителя УНК-1 (600 ГэВ) в направлении лаборатории Гран-Сассо (Италия) и изучения осцилляций нейтрино с использованием установки ICARUS. Ожидаемая область изучения параметров осцилляций в зависимости от условия эксперимента: Δm^2 до 10^{-3} эВ^2 при полном смешивании и $sin^2 2\theta$ до $6{\cdot}10^{-3}$ при $\Delta m^2 \sim 2 \cdot 10^{-2}$ эВ^2.

Introduction

The neutrino oscillations study has become one of the main trends of the elementary particles physics investigations. A wide range of oscillation parameters is investigated: the squared mass difference for the "bare" neutrino Δm^2 - ranging from 100 to 10^{-8} eV^2 and the squared double angle of mixing $\sin^2 2\theta$ from 1 to $10^{-2} \div 10^{-4}$ depending on experimental conditions (Fig.1). The significant range of values Δm^2 $10^{-1} \div 10^{-4}$ eV^2 still exists as not yet studied in neutrino beams of accelerators, which gives the most full and convincing information. In order to study this oscillation parameters range a number of experiments with neutrino beams at the energies 1÷30 GeV from accelerators of CERN, FNAL, KEK, IHEP and such detectors as SOUDAN-2, ICARUS, KAMIOKANDE, DUMAND, BAIKAL [1] - [4] has been proposed.

In the present paper some aspects connected with the possibility to investigate the neutrino oscillation parameters with the help of neutrino beams from UNK-1 (600 GeV) directed to ICARUS facility at Gran Sasso laboratory are discussed. The oscillation parameters range, which can be studied in this experiment is presented in Fig.1. The mutual arrangement of UNK-1 and ICARUS detector is presented in Fig.2.

1. Technique of the oscillation study with neutrino beams

Long-baseline neutrino beams, where neutrinos are registered at long distances from the accelerator, give the unique possibility to carry out the investigations in the field of neutrino physics.

The most peculiar points in such investigations are the big path length of neutrino from the production point to the detector and the great amount of a matter on the neutrino way. That circumstance allows one to reveal some aspects, which under ordinary conditions either do not display themselves at all or display very weakly. As distinct from measurements with neutrinos of the atmospheric and sun origin the experiments with accelerator beams are characterized by sufficiently controlled conditions (the energy, intensity, time structure, beam direction) and have a number of advantages.

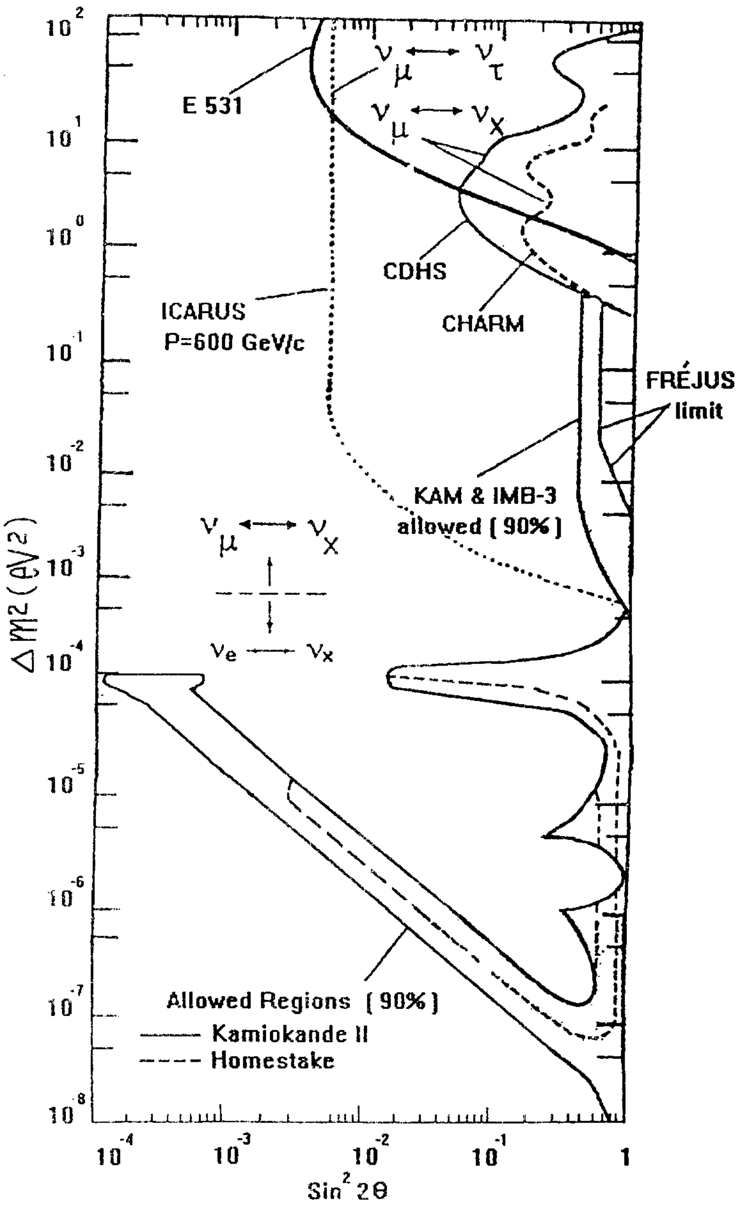

Fig. 1. The sensitivity in the Δm^2 versus $\sin^2 2\theta$ plane of some experiments using accelerator neutrino beams and atmosphere and solar neutrinos and the region suitable to be investigated with UNK-ICARUS.

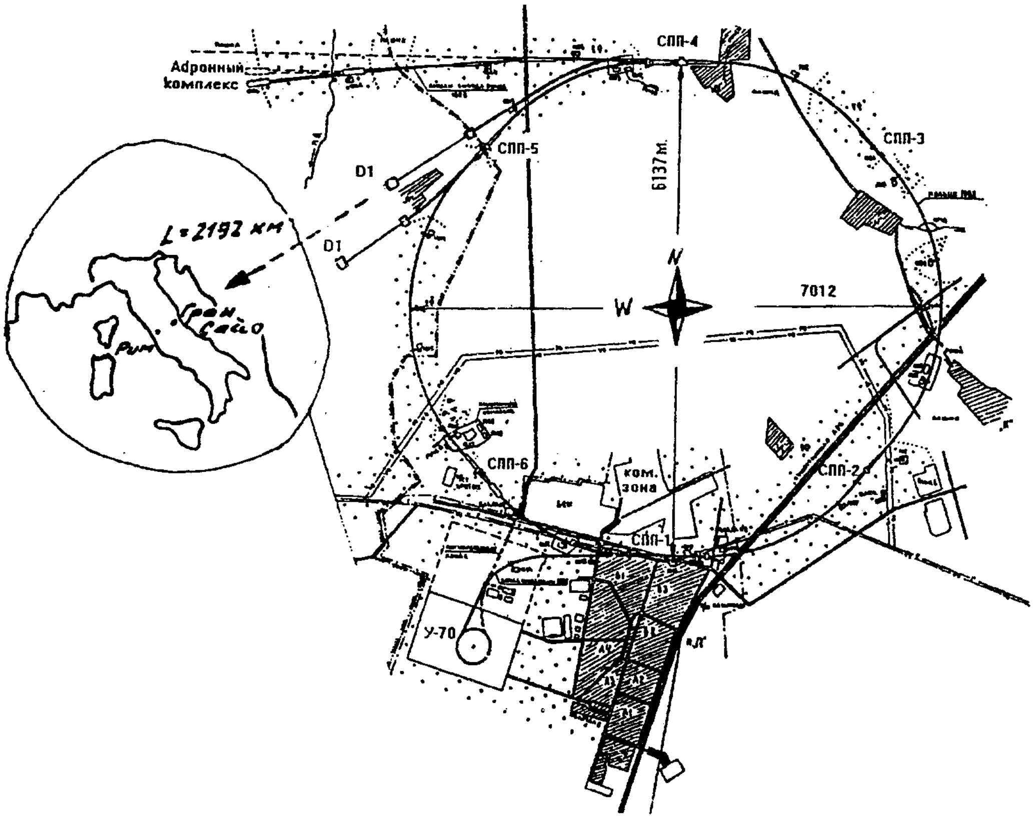

Fig. 2. The mutual position of UNK 54°30′ N.L., 37° E.L. and Gran Sasso 42°27′ N.L., 13°34′ E.L. The distance Protvino – Gran Sasso – 2192 km.

Let us note the following among them:

1. At accelerators it is possible to form the flux of the definite neutrino type with well enough calculated spectrum both for the beam and admixtures.
2. In oscillation experiments it is essential to make the measurements at the different distances. At accelerators it can be achieved both by displacing the detector and by the mounting of two detectors. In this case the nearest detector is the monitor which controls the initial neutrino beam. That partly removes the problems connected with neutrino spectra measurements and determination of a different neutrino type admixture in the beam.
3. During the quasi-monochromatic beams formation it is possible to change the energy of neutrino "parents". That fact allows one to improve sufficiently the spectra calculation accuracy and to change the neutrino energy (that is equivalent to changing the distance between source and detector). Moreover, in that case the oscillation effects are more pronounced, especially in the case of the resonance effect while taking into account the neutrino passage through the matter.

At present the main experimental methods to detect and investigate neutrino oscillations at accelerators have been formulated:

- The measurements of the variation of events fraction, which are produced by the charged current (CC-events) with changing the distance between the accelerator and the detector (L_D) or measurements of this part at fixed L_D with changing the neutrino energy. These investigations require the neutrino spectrum to be known well enough.

- The detection of changing the events ratio, which are produced by the neutral current (NC-events) to CC-events versus the distance L_D and the energy at the given L_D (NC/CC-method).
- The measurement of the equilibrium muons flux, which are produced in a matter in front of the detector (the measurements of the flux, momentum spectrum, charge correlation with distance L_D).
- The direct detection of neutrino of different origin in the same type neutrino flux (for example, the detecting of ν_e, ν_τ excess in ν_μ flux, the changing of equilibrium muons $\mu^\pm$ ratio).

2. Possible investigations with a long-baseline neutrino at UNK-1

2.1. Vacuum oscillations

The neutrino oscillations occur as a result of mixing the neutrino eigenstates with masses m_1, m_2, ... The probability of vacuum oscillations can be represented as [5]

$$P(\nu_l \to \nu_{l'}) = \sin^2 2\theta \cdot \sin^2 \tau, \qquad (1)$$

where θ is the neutrino mixing angle in vacuum; $\tau = (L\pi)/(L_{vac})$; L is the distance between the neutrino source and the detector

$$L_{vac} = \frac{4\pi\hbar c E_\nu}{\Delta m^2} = 2.5(km)\left(\frac{\Delta m^2(eV^2)}{E_\nu(GeV)}\right) \qquad (2)$$

is the vacuum oscillation length; $\Delta m^2 = \mid m_1{}^2 - m_2{}^2 \mid$ is the squared masses difference of mass neutrino eigenstates.

As follows from (1) and (2) the oscillations probability depends on the value $\frac{L\Delta m^2}{E_\nu}$ and in order to move to the lesser values Δm^2 it is necessary to make the measurements at the values $\frac{L}{E_\nu}$ as great as possible.

Under condition

$$L \geq L_o = \frac{1}{\sqrt{2}} G n_e \simeq 3.5 \cdot 10^4 (km)/\rho(g/cm^3), \qquad (3)$$

where L_o is the Wolfenstein reference length; G is the Fermi constant, n_e is the electrons density in matter; the influence of matter on the oscillations of muon neutrino, which compose the main part of neutrino beams from accelerators (up to 99%), becomes essential. That's why for the experiments on investigation of vacuum oscillations the preferable distances are $L \leq 1 \div 2 \cdot 10^3$ km.

2.2. The neutrino oscillations in the matter

Because of non-symmetry of interaction between electron neutrinos and other types of neutrinos (ν_μ and ν_τ) and electrons (due to the contribution of the charged current into the scattering $\nu_e e \to \nu_e e$), the matter of the Earth can essentially change the oscillation process at $L \geq L_o$ - the Mikheev-Smirnoff-Wolfenstein effect [6], [7]. In this case a probability of neutrino transition from one flavor to another depends on the matter density distribution along the beam.

For the medium with the constant density $\rho = \bar{\rho}$ the transition probability of one type of neutrino to another is presented by equation [6]:

$$P(\nu_\mu \to \nu_e) = \frac{\sin^2 2\theta}{\omega^2} \sin^2(\omega\tau), \tag{4}$$

where

$$\omega = \left(1 - 2\cos 2\theta \frac{L_{vac}}{L_o(\bar{\rho})} + \left(\frac{L_{vac}}{L_o(\bar{\rho})}\right)^2\right)^{\frac{1}{2}}. \tag{5}$$

From (4), (5) it follows that in the matter with $\rho = \bar{\rho} = const$ the effective mixing angle and the oscillations length are equal accordingly

$$\sin 2\theta_m = \frac{\sin 2\theta}{\omega}; L_m = \frac{L_{vac}}{\omega}. \tag{6}$$

The probability of transition $P(\nu_l \to \nu_{l'})$ in the matter can vary globally in comparison with that in vacuum. The matter can both suppress the oscillations (at $\cos 2\theta \sim 0$) and increase them. In resonance case [7]

$$\frac{L_{vac}}{L_o} = \cos 2\theta \tag{7}$$

we have $\omega = \sin 2\theta$ and the oscillations amplitude becomes equal to unity at any mixing angle θ. According to this fact, at the given observation level for the transition probability $P(\nu_l \to \nu_{l'})$ the experiment imposes other limitations on the values Δm^2 and $\sin^2 2\theta$ unlike those in the case of vacuum oscillations.

Let us note that inside the Earth resonance condition (7)

$$\frac{L_{vac}}{L_o} = \frac{E_\nu \rho}{1.4 \cdot 10^4 \Delta m^2} \tag{8}$$

is carried out in the wide range of values Δm^2 and $\sin^2 2\theta$ which are admitted by the modern experimental data with account for the possibility to change the neutrino energy: $1 < E_\nu \leq 10^3$ GeV. In that case the optimal base for experiments is $L \sim 2{\cdot}10^3 {\div} 1.2{\cdot}10^4$ km.

The oscillations $\nu_l \to \nu_{l'}$ in the medium with a variable density are described by the Shrodinger equation for the two-component amplitude

$$\Psi = \left| \begin{matrix} \nu_l \\ \nu_{l'} \end{matrix} \right\rangle,$$

$$i\frac{d\Psi}{dt} = H\Psi, \tag{9}$$

where

$$H = \pi \begin{pmatrix} \frac{\cos 2\theta}{L_{vac}} - \frac{1}{L_o(t)} & -\frac{\sin 2\theta}{L_{vac}} \\ -\frac{\sin 2\theta}{L_{vac}} & -\frac{\cos 2\theta}{L_{vac}} + \frac{1}{L_o(t)} \end{pmatrix} \tag{10}$$

and $t = \frac{x}{c} = x$. It is possible for a practical application to equate (9) to the second order equation for the amplitude $| \nu_{l'} > \equiv \xi$ by excluding the component $| \nu_l >$

$$\frac{d^2\xi}{dt^2} + f(t)\xi = 0, \tag{11}$$

$$f(t) = \pi^2 \left(\frac{1}{L_o{}^2(t)} - \frac{2\cos 2\theta}{L_{vac}L_o(t)} + \frac{1}{L_{vac}^2}\right) + i\pi\frac{d}{dt}\left(\frac{1}{L_o(t)}\right) \tag{12}$$

with initial conditions for the beam $\nu_{l'}$

$$\xi(0) = 0; \qquad \frac{d\xi(0)}{dt} = i \sin 2\theta. \tag{13}$$

The solution of equation (12) gives the transition probability $\nu_l \rightarrow \nu_{l'}$

$$P(\nu_l \rightarrow \nu_{l'})(t) = \mid \xi(t) \mid^2. \tag{14}$$

In particular, the Wolfenstein result (5) follows from (12) at $\rho(t) = \overline{\rho}$. It is important to note that the sign of the amplitude $\overline{\nu_l} l$ - scattering $(l = e, \mu, \tau)$ is opposite to that of the amplitude $\nu_l l$ - scattering which corresponds to the replacement $L_o \rightarrow -L_o$. It means that the resonance can occur either for ν or for $\bar{\nu}$ but not for both of them simultaneously. So, the observation of oscillations in the matter gives a principal possibility to determine the sign of $L_{vac} \sim ({m_1}^2 - {m_2}^2)^{-1}$.

Let us use equation (12) in order to describe the neutrino oscillations inside the Earth, setting the distribution density according to [10]. Note that the neutrino oscillations inside the Earth at enormous distances must be different from that in vacuum, because the Wolfenstein length L_o for characteristic densities $\rho \sim 3 \div 10$ g/cm^3 is about $3500 \div 12500$ km that is comparable with the Earth diameter $\oslash$. It follows from an accidental coincidence by an order of magnitude for two values which are physically different - the reverse Fermi constant $\frac{1}{G} = 2 \cdot 10^{32} cm^{-2}$ and the quantity of electrons per area unit along the Earth diameter $n_e^{'} \simeq \frac{N_A}{2} \int_0^{\oslash} \rho(t) dt \simeq 3 \cdot 10^{33}$ cm^{-2}.

Fig.3 (a,b,c) shows how the oscillations change their behaviour, while a neutrino beam passes through the matter, in comparison with the vacuum. Here the available parameters were calculated for the distance 2200 km (the distance from UNK to Gran Sasso laboratory) and for neutrinos with $< E_\nu >= 27.9$ GeV (Fig.3 a); $< E_\nu > = 49.5$ GeV (Fig.3 b), $< E_\nu > = 81.3$ GeV (Fig.3 c). The momentum of neutrino "parents" – π^+-mesons – for monochromatic beams is equal to $P_\pi = 70$, 140, 280 GeV, correspondingly. On each figure the attainable oscillations parameters are calculated for the measurement of the transition probability $P(\nu_\mu \rightarrow \nu_e)$ with the accuracy up to $10^{-1}, 3 \cdot 10^{-2}, 10^{-2}$. The main result: the account of the matter worsens the available level on Δm^2 under maximal mixing, but at the same time it allows one to go deeper into the region of lesser mixing angles.

Another important effect, which occurs while a neutrino beam passes through the matter, is shown on Fig.4. This picture shows the change of $P(\nu_\mu \rightarrow \nu_e)$, with the neutrino energy at L=2200 km and $\Delta m^2 = 2 \cdot 10^{-2}$ and $\sin^2 2\theta_\nu = 0.78$ (the best fit for parameters Δm^2 and $\sin^2 2\theta_\nu$ obtained in the experiment KAMIOKANDE [9]).

Due to oscillations increase, occurring under "resonance" conditions, there is an area on the plane $(\Delta m^2, \sin^2 2\theta_\nu)$, where the oscillation probability is close to unity. One can see that the comparison of the results of a detector exposure at variable neutrino energies (for example, at the energy range from $30 \div 40$ GeV to ~ 80 GeV) can give an additional indication of the existence of an oscillation effect. Here the initial neutrino beam intensity can change by $2 \div 3$ times.

Besides the neutrino oscillations parameters study in experiments with long-baseline neutrinos a possibility to observe other fundamental physical effects occurs at the same time.

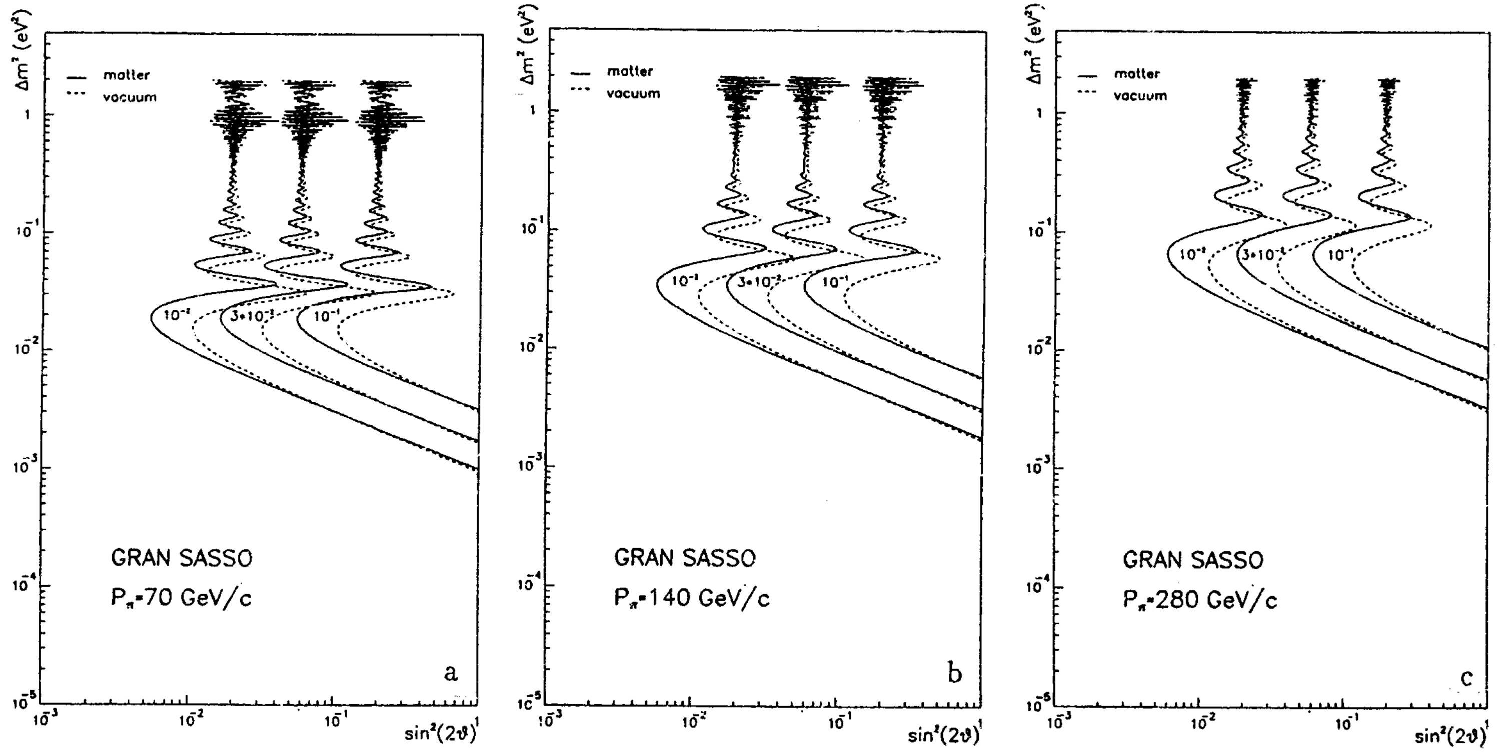

Fig. 3. a) The sensitivity of the Protvino - Gran Sasso experiment for the narrow band neutrino beam with $<E_\nu> \sim 27.9$ GeV, $p_{\pi^+} = 70$ GeV. $P(\nu_\mu \to \nu_e)$ measured with the accuracy up to 1%, 3% and 10%; b) the same as in fig. 4, but $<E_\nu> \sim 49.5$ GeV, $p_{\pi^+} = 140$ GeV; c) the same as in fig. 4, but $<E_\nu> \sim 81$ GeV, $p_{\pi^+} = 280$ GeV.

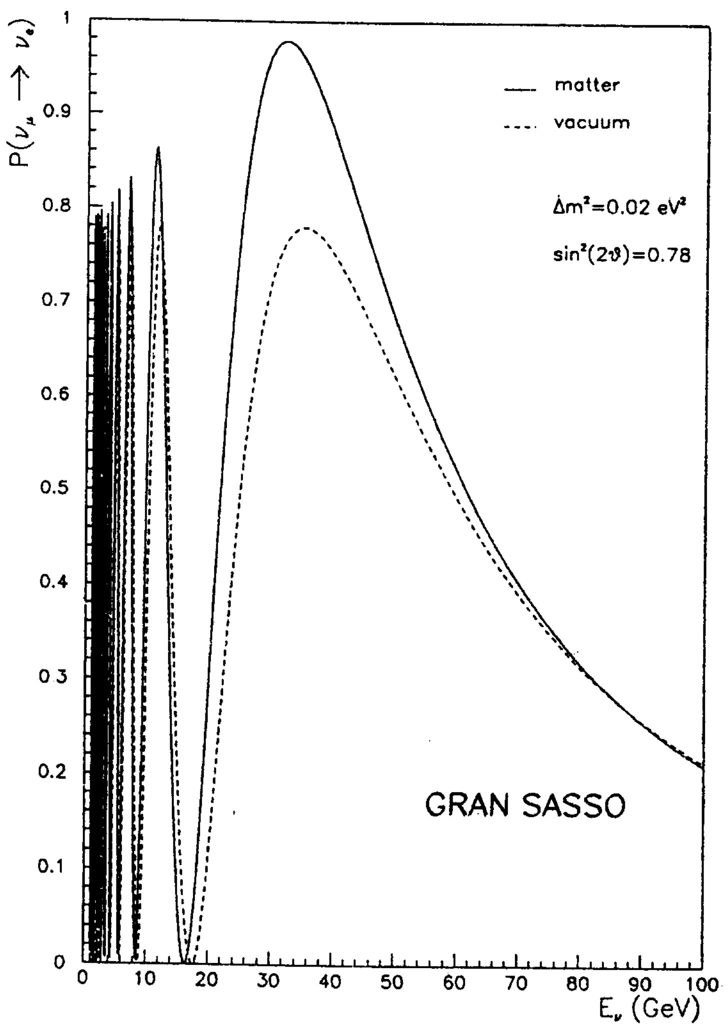

Fig. 4. The $P(\nu_\mu \to \nu_e)$ dependence on the energy calculated for the Protvino - Gran Sasso experiment at Δm^2=0.02 eV^2, $sin^2 2\theta$=0.78 (KAMIOKANDE [9]).

2.3. T-(CP) invariance breaking

Mixing masses and angles in the lepton sector are connected directly with the neutrino oscillations parameters. In the case of three generations one of the mixing parameters is responsible for the T-invariance breaking and the corresponding effects can be discovered in experiments with long-baseline neutrinos, where they moreover can increase due to the presence of matter [10]. It should be noted that in most cases in astrophysics neutrino experiments it is only the transition probability that can be observed for electron neutrino $P(\nu_e \to \nu_e)$ and which doesn't depend on phase that breaks the T-invariance. Another peculiar point, which distinguishes the experiments with long-baseline neutrinos on the Earth, is the symmetry for the replacement $x \to -x$ for the matter on the neutrino path and this fact is very important for the effect observing.

2.4. The neutrino decay in the matter

Experiments with a long-baseline neutrino can be used for searching the neutrino decays, caused by the interaction with matter [11]. If N_e and N_n are correspondingly the electron and neutron densities of the matter then the moving of neutrino in this matter can be described by the Dirac equation which is analogous to that for the electron in the external field $eA_\mu = (\rho, 0)$, where for the electron neutrino $\rho = G\sqrt{2}N_e - \rho'$, $\rho' = -GN_n/\sqrt{2}$ and for the muon and tau neutrino $\rho = \rho'$. Since the signs of scattering amplitudes ν and $\overline{\nu}$ are different, the energy levels ν and $\overline{\nu}$ in the matter are also different

$$E_{\nu/\overline{\nu}} = \sqrt{p_\nu{}^2 + m_\nu{}^2 c^4} \pm \rho. \tag{15}$$

This means that in the matter the decays ν (or $\overline{\nu}$ - which depends on the neutrino type and N_n) are possible together with the emission of a massless (or sufficiently light) scalar particle, for example, majoron [12]: $\nu \rightarrow \overline{\nu} + \alpha$ or $\overline{\nu} \rightarrow \nu + \alpha$ (in this case the diagonality of majoron bonds forbids such a decays in a vacuum).

As it is clear from (15), in the matter $\overline{\nu_\mu}$ is heavier than ν_μ (which forms in general the neutrino beams in accelerators) and therefore the decay $\overline{\nu_\mu} \rightarrow \nu_\mu + \alpha$ is possible only in the case of $\overline{\nu_\mu}$ beam presence. The probability of such a decay is very small - $\tau(\overline{\nu_\mu} \rightarrow \nu_\mu \alpha)$ $= 50$ s, however it has the bright signature: the production of muons of different sign (that is μ^-) $\nu_\mu n \rightarrow \mu^- + X$ in spite of positive muons expected from $\overline{\nu_\mu}$. That's why the detector must distinguish μ^+ and μ^-.

The presence of the effect doesn't depend on the neutrino mass and in particular will take place for the massless neutrino. The decay probability in the matter doesn't depend on neutrino energy (while for the ordinary decays in a vacuum $\sim E_\nu^{-1}$) and one can choose the energy E_ν for reasons of a beam creating and a neutrino registration at long distances.

2.5. The heavy neutrino

The possibility of searching and measuring the mass M of a neutrino with the energy E_ν is determined by the difference in the time of flight of massive and massless neutrinos while passing the distance L: $\Delta t \simeq (L/2c)(Mc^2/E_\nu)^2$. If the time of flight is measured with the accuracy ~ 1 ns (the work of an accelerator and detector must be also synchronized with the same accuracy) then while registering neutrinos at $E_0 \simeq 2$ GeV and L $\simeq 10^4$ km one can obtain the limit on the neutrino mass M ≤ 1 MeV/s^2. For the UNK this accuracy is reachable in principle (the signals from delayed (heavy) neutrinos can come in the interval between the pulses caused by the accelerator bunches).

3. The ICARUS detector for neutrino oscillations investigations

At the Gran Sasso lab[1] which was created by the Italian National Nuclear Physics Institute, the underground ($\sim 4000 g/cm^3$) investigation center to study a number of astrophysical and some fundamental problems of the elementary particles physics is under construction now (see, for example, [13]).

At this lab it is planned to place four massive detectors - GALLEX [14], MACRO [15], LVD [16] and ICARUS [2], [17]. The last three facilities can be used in principle to register the signal from neutrino beams at accelerators (CERN, Protvino, etc.).

In general the ICARUS detector has been optimized for studying the astrophysical problems and discovering the proton decay, however, it will be the ideal facility for the

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[1] Central Italy, ~120 km to the east of Rome; 42°21′ N.L.; 13°34′ E.L.

neutrino oscillations investigations because it is possible to use here all the methods of oscillations detection, the study of equilibrium muons flux, the NC/CC-correlations using, the CC-events variation with energy changes and mainly the direct observation of the presence (and/or surplus) ν_e and ν_τ - events in ν_μ - beams. Moreover, at the Protvino - Gran Sasso ~ 2200 km distance the effect of beam passing through the Earth matter can influence significantly, the oscillations detections and improves the conditions of the oscillations detection. The ICARUS detector is shown on fig.5, and its characteristics are given in Table 1.

In ICARUS the neutrino interactions are identified by the recoil electrons from secondary charged particles, registered by the time-projection chamber with the liquid argon filling. Because of an electron drifting in a homogeneous electric field the charge is registered on the registering planes and the three-dimensional electron image is formed. The two space coordinates of the analyzed track points are determined by coordinates at which the drifting electrons come on the registration plane; the third coordinate is determined by the drifting time. The main difficulty in realizing the image formation in a detector with a liquid argon filling is connected with the ability of ionization electrons to drift at large distances. This problem had been solved for the 3 T detector prototype [18]. The detector is of high space resolution (from ± 1 mm to hundreds of mkm) and the good energy one (~ 3 % for $e^{\pm}$ and γ with energy 1 MeV).

Table 1. ICARUS detector parameters

Internal vessel		External vessel
Shape	Horizontal cylinder with domed ends	Horizontal cylinder with flat ends
Diameter	16.0 m	18.2 m external
Length	20.0 m	24.8 m external
Volume	4180 m^3 net, total	-
Filling ratio	0.90 to 0.95	-
Design pressure	0.2+hydro	0.1 MPa
Design temperature	85°K	20°
Material	AISI 304 L	9% Ni steel
Hull structure	Double, compartment	Single, reinforced rings
Ends structure	Double, compartment	Sandwich, partially open
Body weight	~ 750 t total	~ 500 t total

4. Nearby detector

In this experiment it is proposed to use two detectors, placed at different distances from the accelerator. The task of the first detector, placed directly near the neutrino channel, is to measure the zero point of count - the muon neutrino flux - by registering the number of interactions in the nonoscillating beam. In order to decrease the systematic errors, connected with an instability of a neutrino beam intensity, the distance to the near detector should be chosen with account for the necessity of minimizing the muons, background produced due to mesons decays. As the neutrino beam from the accelerator is deepened at the angle of ~9, 5° to the horizon, then, starting from the approximate

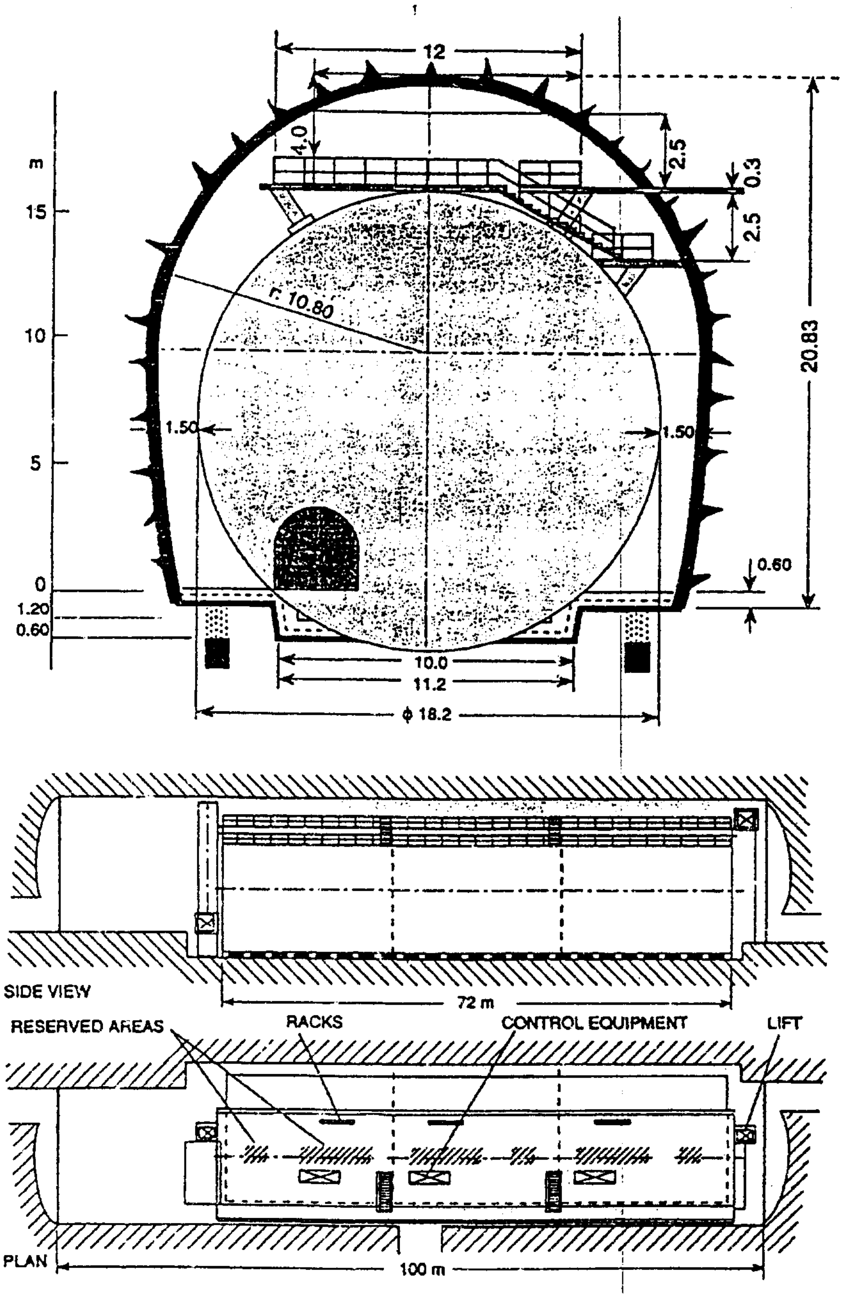

Fig. 5. The conceptual view of the Hall C at Gran Sasso with the ICARUS detector. The longitudinal view of the Hall C at Gran Sasso showing conceptually the installation of the three ICARUS cryostat modules.

depth of a shaft in which the nearby detector is situated, the distance to the detector had been chosen to be ~ 1000 m.

At the first stage of the experiment the oscillation effect is investigated by comparing the number of muon neutrino interactions at the first and second detectors. The Monte-Carlo calculation shows that the requirement of a direction and divergence stability for the neutrino beam can be decreased with the help of a definite radius selected for the cylindrical effective volume of the nearby detector.

At the first step of the experiment the main requirements are the following:

1. The detector must quite efficiently register the events of a muon neutrino interaction in the charged current channel with energies $E_\nu = 20 \div 100$ GeV.
2. The apparatus function of the first detector and the registration efficiency must correspond to the analogical parameters of the remote detector and provide the prediction of neutrino flux in the remote detector with the systematic error up to $\sim 3 \div 1\%$.

It is assumed that the first detector (fig.6) will consist of 60 magnetized iron filters 10 cm thick ($\vec{B} \sim 1.5\ T$). The traversal size of filters is 3x3 m^2. Between the iron filters the proportional counters are placed. The planes of horizontally situated counters alternate with the planes in which the counters are situated vertically. Proportional counters are made of an aluminum profile of a square section 60×60 mm^2, the counter length is 3 m. The total number of counters is 6000.

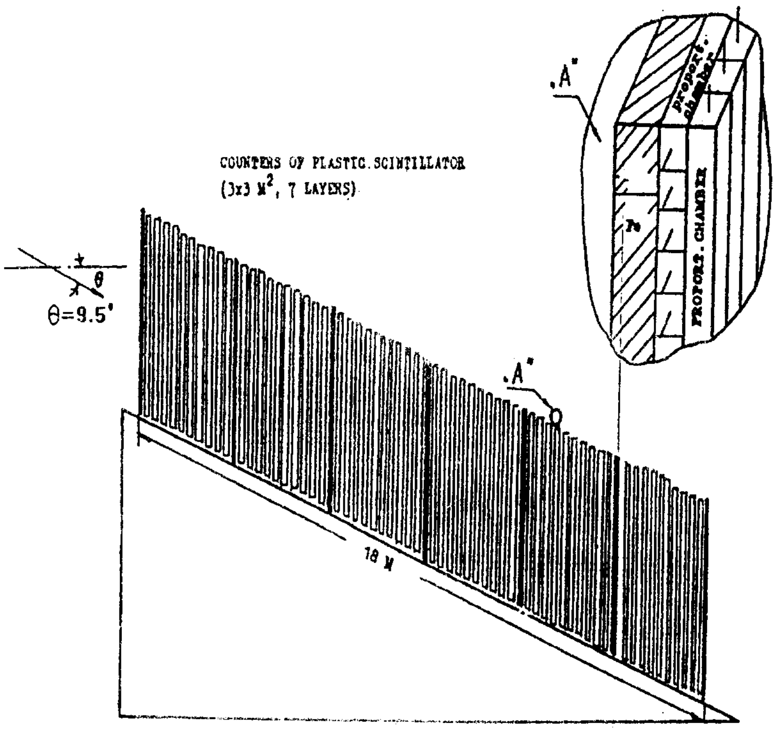

Fig. 6. The nearby detector. The modular construction. 60 modules, each containing 10 cm Fe, S=3x3 m^2 with 2 layers proportional chambers.

In front of the detector and behind the 10-, 20-, 30-, 40-, 50-, 60-th filters of iron the scintillation counters profiles are situated (7 planes, $S = 3 \times 3\ m^2$). The trigger of an event is provided while any of three layers of arranged scintillation counters (C_{i-1}, C_i, C_{i+1}) coincide when the signal in counters of anticoincidence $\bar{A}$ situated before the detector is absent. The energetic resolution for a hadron cascade in the calorimeter with such a structure is $\Delta E/E = 0.7/\sqrt{E}$ ([E] in GeV). In the detector the neutrino events in the charged current channel will be selected. The events must have a track, passing without the visible interaction ≥ 300 cm Fe ($\sim$ 15 nuclear lengths), which corresponds to the muon range with the energy $E_\mu \geq 5$ GeV. It allows one to select the muon track from the cascade of hadrons, which have been produced during the neutrino interaction.

The Monte-Carlo calculations show, that in order to reach systematic errors $\sim 1 \div 3\%$ when calculating the ν_μ flux with the help of two detectors system in this experiment it is necessary:

- to hold the direction and divergence stability of neutrino "parents" with the accuracy better then ±0.00015 rad.
- in this case the effective volume of the nearby detector must have the cylindrical form with the diameter 48 cm (the effective mass is $\sim$ 14 t Fe).

Further, the nearby detector can be reconstructed for the electron neutrino registration. In this case one can achieve the accuracy of ΔP measurements up to values $1 \div 0.1\%$.

5. Neutrino beams characteristics

The neutrino beam in the Gran Sasso lab direction can be formed with the help of the proton beam, which is extracted from the fifth straight section of UNK-1. For the Gran Sasso direction the beam is rotated in the equilibrium orbit plane of UNK-1 by 16.3° (northward) and then directed downward into the 9.5° earth depth (Fig.2).

The main elements of the remote neutrino complex for the neutrino beam formation are: the system of the fast proton extraction, the proton beam transportation channel, the target station, the focusing or forming facility for π and K-mesons, the decay channel, the hadron absorber.

It is possible to carry out physical investigations at the remote neutrino complex of UNK-I in different beam types:

1. Neutrino beams with the wide energetic spectrum.

   The most intensive neutrino beams can be obtained by using axially-symmetrical current shells (horns and parabolic lenses). Such focusing systems allow one to form both neutrino and antineutrino beams with a small admixture of antineutrino and neutrino correspondingly.

   In order to form a wide neutrino spectrum the systems of parabolic lenses of IHEP [19] or Horn type systems can be used [20]. In Table 2 the ν_μ flux I_ν values are given for the area with the radius $\sim$ 50 m, and also the number of neutrino interactions N_{ev}/day is calculated for detector with the mass $1.5 \cdot 10^4$ t (which corresponds to the ICARUS detector characteristics) with the help of parabolic lenses systems. In this case the number of cycles in the accelerator is ~ 720/day with $3 \cdot 10^{14}$ protons per pulse. The energetic spectra of neutrinos for the three working regimes for focusing facilities are given on fig.7. For the focusing system of two horns the calculation at $< E_\nu > \simeq 69$ GeV leads to the registration in the detector N_{ev}/day $\simeq 30$.

   Besides axially-symmetrical focusing systems one can use the quadrupole lenses for the forming neutrino beam with the wide energetic spectrum. The simplest system of that kind is the triplet of quadrupole lenses, forming the beam of "parents" from the point to parallel for one pulse of secondary particles. Because the objectives of quadrupole lenses focus the particles of both signs of charge, the neutrino beam, formed by such a system, consists of neutrino and antineutrino in correlation 2:1. The neutrino beams parameters for this case, formed at the ICARUS facility are given in Table 3 (the energy of the original proton beam is 600 GeV, the intensity - $3 \cdot 10^{14} ppp$, the length of decay base - 500 m).

2. The neutrino beams with the narrow spectrum.

Such monochromatic neutrino beams from π^+ meson decay with $\Delta P_\pi / P_\pi \sim$ of 20% can be made with the help quadrupole lenses system. The calculation of neutrino interaction yield in the detector at different energies of neutrino "parents" are given in Table 4.

The totality of the calculated data, obtained for different variants of neutrino beams forming, shows that during the working period of the accelerator (1÷2 months) the provided registration in the detector is up to ~ 1000 interactions [21].

Table 2. Parameters of neutrino fluxes through the ICARUS detector for the neutrino beam with the wide energetic spectrum (some variants of focusing systems of the IHEP parabolic lenses).

#	$<E_\nu>$, GeV	I_ν/prot.	N_{ev}/day
1	19.4	$.286 \cdot 10^{-5}$	9.3
2	39.3	$.470 \cdot 10^{-5}$	30.6
3	51.6	$.397 \cdot 10^{-5}$	34.1
4	40.9	$.548 \cdot 10^{-6}$	3.7

Table 3. Parameters of neutrino fluxes through the ICARUS detector for the neutrino beam with the wide energetic spectrum (some variants of focusing systems of quadrupole lenses).

Focusing system	$N_{int.}$/day	$< E_\nu >$ GeV
Triplet of quad. lenses		
P_π = 50 GeV/s	4.8	33
P_π = 100 GeV/s	7.5	43
P_π = 200 GeV/s	10.2	68
Horn + reflector	21.9	65
Without focusing	3.9	51

Table 4. Parameters of neutrino fluxes through the ICARUS detector for some variants of the monochromatic neutrino beam (focusing systems of quadrupole lenses).

E_π, GeV	$< E_\nu >$, GeV	I_ν/prot.	N_{ev}/day
70	27.9	$.202 \cdot 10^{-6}$	0.93
140	49.5	$.363 \cdot 10^{-6}$	2.73
280	81.3	$.187 \cdot 10^{-6}$	2.50

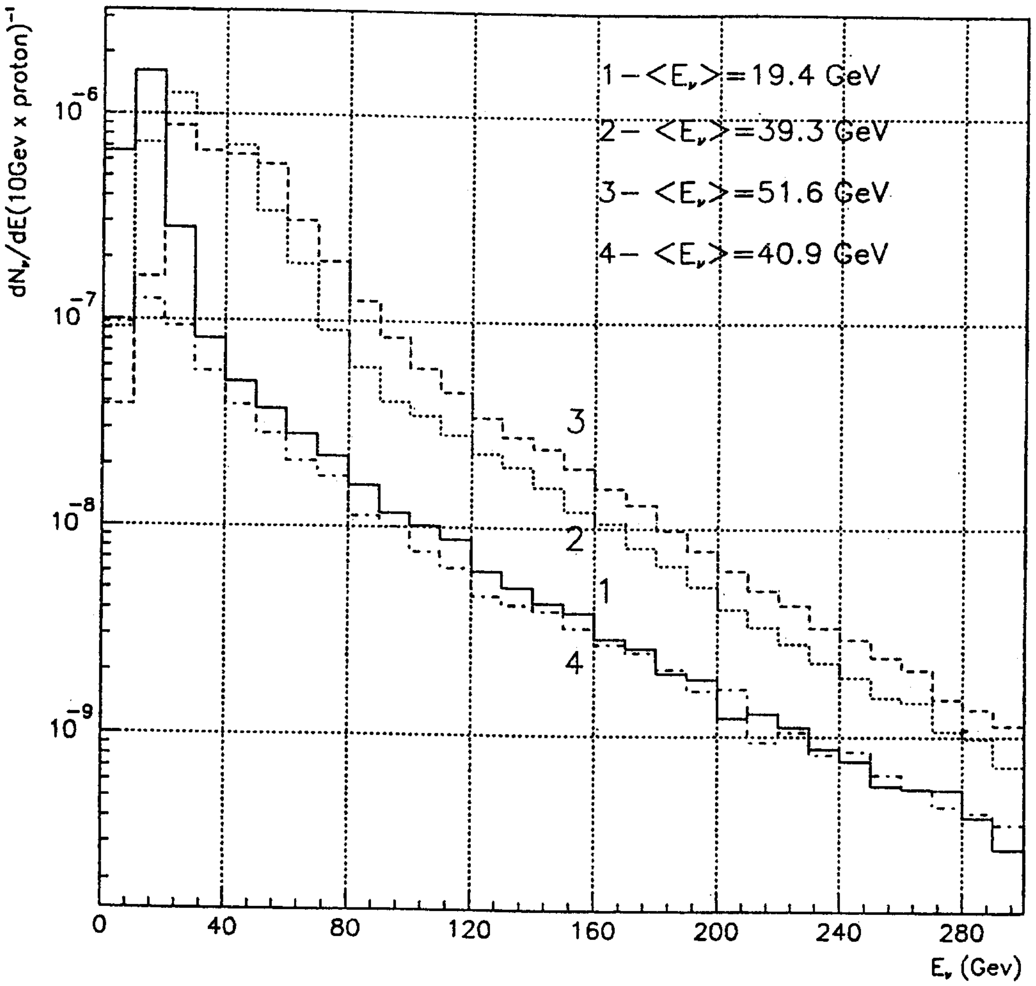

Fig. 7. The energy spectra of the wide band neutrino beams from UNK-I, formed by a focusing system of the IHEP parabolic lenses. (Variant 4 presents the parameters of the unfocused neutrino beam.)

6. Logic of the experiment

It is obvious, that at the first stage of the experiment one should be oriented on the equilibrium muons flux registration. The hole neutrino flux in the detector with the beam area S is given by the following expression

$$\frac{dN}{dE_\nu} = S\left(\frac{d^2N_\nu}{dE_\nu dS}\right). \tag{16}$$

The number of charged current events $\nu_\mu + N \to \mu^- + \ldots$ in the detector with mass M is

$$N_c = \sigma_0 N_A M \int E_\nu \left(\frac{d^2N_\nu}{dE_\nu dS}\right) dE_\nu \sim < E_\nu >, \tag{17}$$

where $\sigma = \sigma_0 E_\nu$, $\sigma_0 = 0.72 \cdot 10^{-38}\ GeV^{-1}cm^2$; N_A is the Avogadro number.

$$\frac{d^2N_\mu}{dE_\mu dS} = \int \frac{d^2N_\nu}{dE_\nu dS} F(E_\mu, E_\nu) dE_\nu, \tag{18}$$

$$F(E_\mu, E_\nu) = \frac{N_A \sigma_0 (E_\nu - E_\mu)}{A_0(1 + B_0 E_\mu)}. \tag{19}$$

The constant $A_0 = 2 \cdot 10^{-3} GeV \cdot cm^2 \cdot g^{-1}$ and $B_0 = 1.9 \cdot 10^{-3}$ GeV^{-1} are connected with energetic losses of muons

$$-\frac{dE_\mu}{d(\rho\xi)} = A_0(1 + B_0 A_\mu), \tag{20}$$

where ρ is the substance density.

As far as the average number of equilibrium muons, that accompanies the one neutrino with the energy E_ν, is equal to

$$\Pi_\mu(E_\nu) = \int_0^{E_\nu} F(E_\mu, E_\nu) dE_\mu = \frac{N_A \cdot \sigma_0 \cdot {E_\nu}^2 \cdot f(\eta)}{2A_0}, \tag{21}$$

where

$$f(\eta) = \frac{2}{\eta^2}\left[(1+\eta)\ln(1+\eta) - \eta\right]; \eta = B_0 E_\nu, \tag{22}$$

then the equilibrium muons flux is determined by the expression

$$\frac{dN_\mu}{dS} = \int \Pi_\mu(E_\nu) \frac{d^2E_\nu}{dE_\nu dS} dE_\nu \sim < {E_\nu}^2 > . \tag{23}$$

With the 600 GeV energy of accelerated protons at the distance ~2200 km and the decay channel ~500 m for the ideal focusing and conditions without focusing, one can expect the values of neutrino flux parameters through the ICARUS detector, given in Tables 2-4.

Under the real conditions the proton intensity will be $\sim 3 \cdot 10^{14}$ at 120 s cycle, i.e. there will be ~720 cycles/day. It will allow one to register under the ideal focusing of the wide spectrum several hundreds of equilibrium muons in the month's exposure. It will provide the measurement of a muon flux decreasing at the one percent level. By taking into account the systematic errors one can make tests of Kamiocande data [9]. At the second stage it will be possible to start the beams forming with a narrow spectrum and make a more detailed study of a neutrino flux changing effect, if discovered.

7. Investigation zones of the long-baseline neutrinos complex (LBNC)

7.1. Placing and main elements of LBNC

There are two principal real possibilities of placing LBNC at UNK (Fig.9):

- to place LBNC on the base of the planned proton extraction from SS-4 (Fig.8);
- to develop the fast extraction on the base of SS-5 [21].

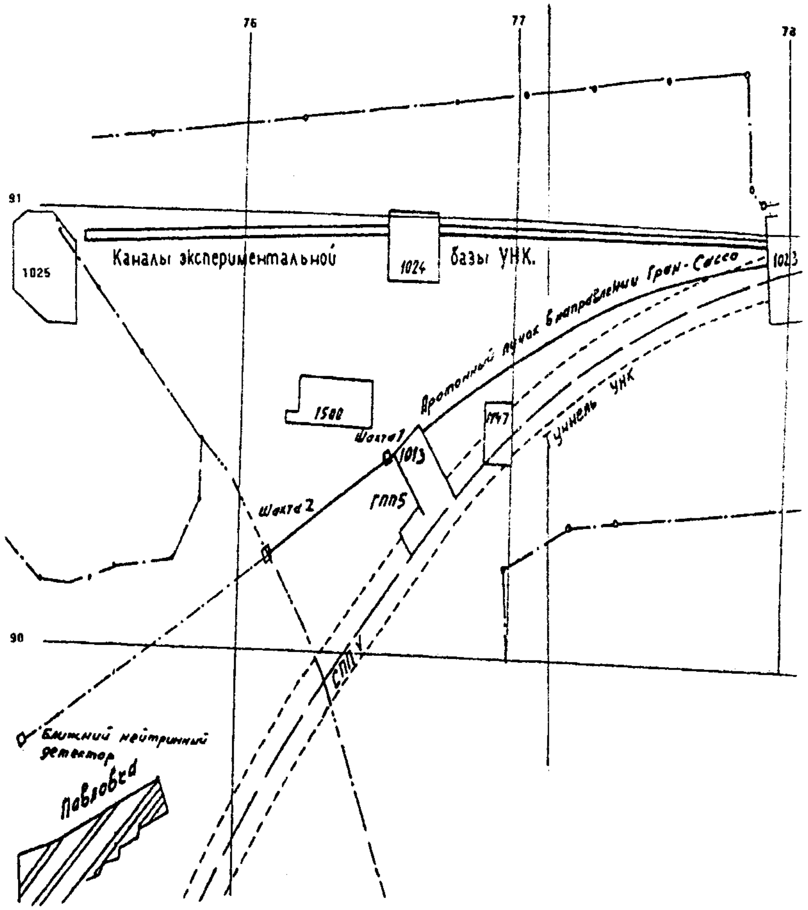

Fig. 8. The plan of the neutrino channel position towards Gran Sasso at the proton beam extraction from SS-4.

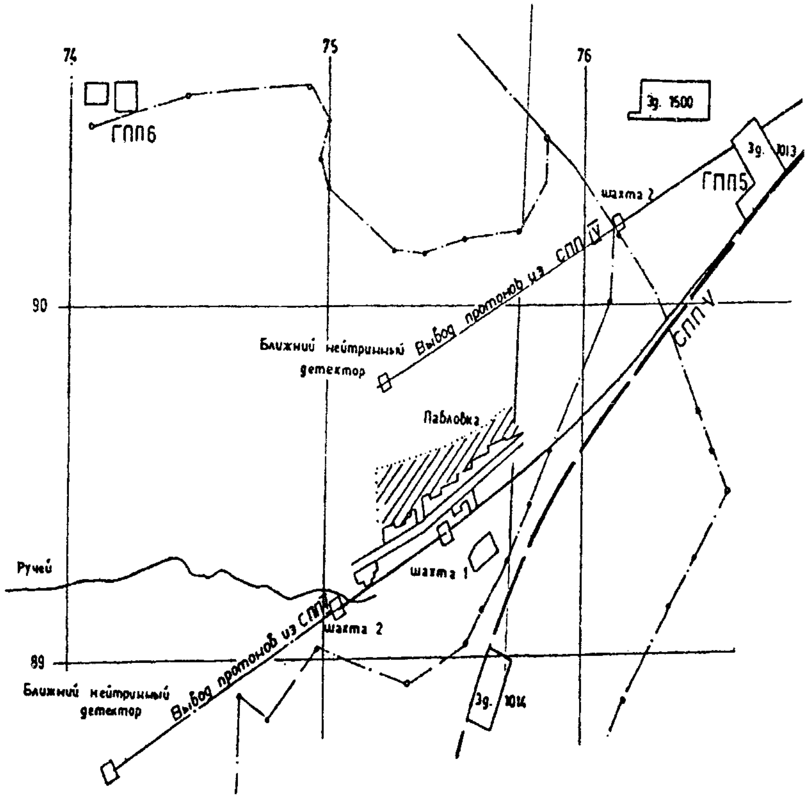

Fig. 9. The schematic view of the mutual position of Gran Sasso, service buildings and the UNK tunnel.

For the first version the proton beam (to be aimed at Gran Sasso) should be rotated by 26.5° southward, and for the second case the rotation angle is 16.3° northward. The difference in rotation angles of the proton beam when transportated in the UNK - Gran Sasso direction will not adversely affect the project cost. But the version of beam extraction from the SS-5 may turn out to be more expensive due to the complicated geological structure and the ground alienation. It is noteworthy that due to the LBNC placement on the base of the SS-4 a possibility to create a neutrino beam for the NESTOR experiment has been practically lost [21].

The most feasible is the variant of beam extraction from the technological straight section SS-4, where the fast extraction system of a proton beam in the direction of the hadron and neutrino complex (Fig.10) is planned. In this case the beam is extracted from the accelerator by the fast extraction system and directed to the planned proton trace. In order to transfer the beam in the Gran Sasso direction it is necessary to create the additional underground tunnel, adjoining the planned proton tunnel at its initial part. In order to direct the beam in the Gran Sasso lab direction it is necessary to rotate the beam by 26.5° and direct downward at 9.7°.

The main elements of this section:

- the proton extraction system;
- the proton beam transportation system up to the target station.

The focusing facility to form π and K-mesons beams is situated after the target station. Behind the focusing facility the decay channel begins, in which the neutrino beam forming due to π and K-mesons decays takes place. At the end of the decay channel the hadron absorber is situated.

It is proposed to place the nearby neutrino detector D-1, which allows one to measure the initial neutrino flux at the distance ~ 1000 m from the end of the decay channel. The preliminary arrangement of LBNC UNK is shown on Fig.10,11.

LBNC consists of:

- the beam transferring system from UNK-1 to the transportation channel;

- the zone of proton beam transportation channel to the neutrino channel target, consisting of a horizontal part and a zone of a beam "deepening" in the Gran Sasso lab direction;

- the target station zone;

- the focusing system zone;

- the decay channel zone;

- the hadron filter zone;

- the beam monitoring system;

- the near neutrino detector zone.

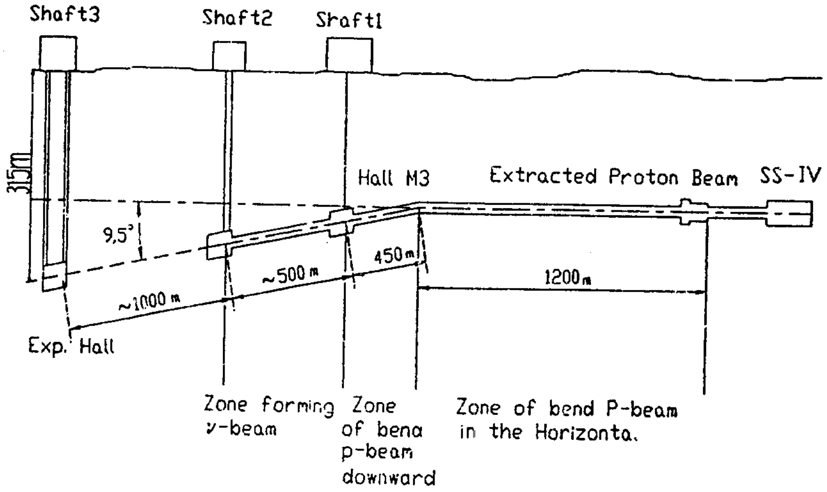

Fig. 10. The neutrino complex profile towards Gran Sasso.

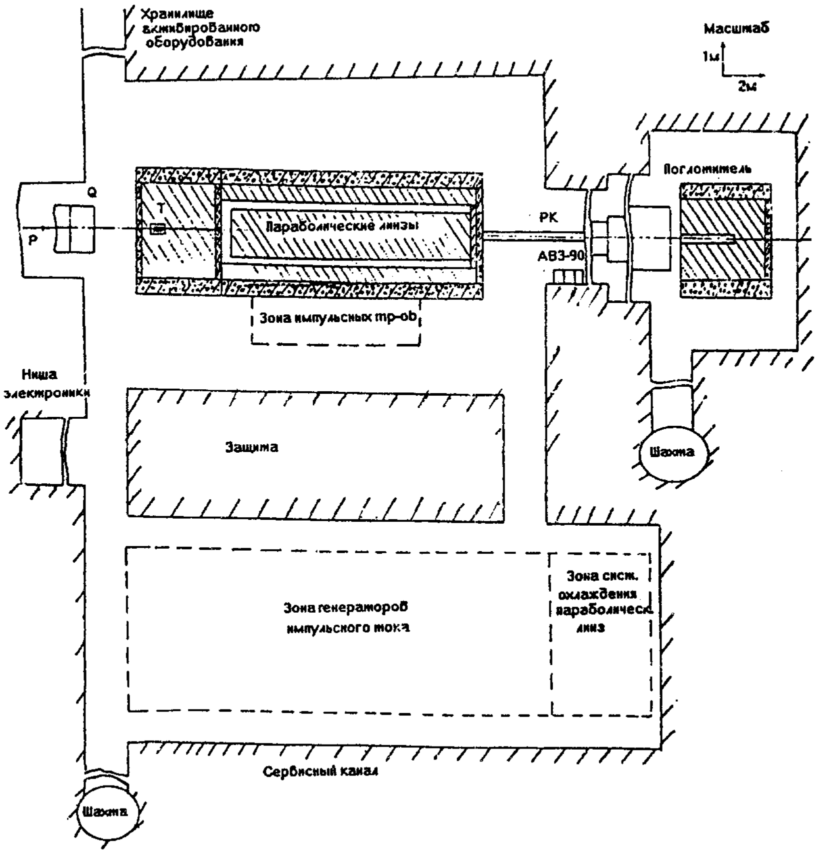

Fig. 11. NFF (neutrino focusing facility) with parabolic lenses.

7.2. The proton beam extraction system from UNK-1 to the transportation channel

The first stage of UNK serves for the proton beam acceleration up to 400 GeV energy and its injection into the superconducting second stage. It can be used as a single accelerator at 600 GeV energy with the intensity $6 \cdot 10^{14}$ protons/cycle, if the intensity of an injected beam from U-70 is $5 \cdot 10^{13}$.

The following types of fast beam extraction are supposed: one turn and multiple turn.

The working regimes are:

1) the injection of twelve current pulses from U-70 is carried out on the injection plateau 6 x 12 = 72s;

2) the acceleration of a proton beam to 600 GeV energy during 20 s;

3) the duration of a magnet cycle plateau at 600 GeV energy is 20 s;

4) the duration of a magnet cycle back front is 5 s.
And in this case the average proton extraction intensity per cycle
is $5 \cdot 10^{12}$ p/s.

7.3. Zone of a proton beam transportation from UNK-1 to the beam forming zone

When creating a beam transportation channel it is desirable, if possible, to meet the following conditions:

1) the channel construction must not break the accelerator working regime;

2) the maximal volume of drifting must be carried out under good geological conditions;

3) the channel equipment must be standardized with that of the accelerator.

Taking this fact into account it is reasonable to divide the proton beam transportation channel into two sections. The first section provides the rotation in the horizontal plane by 26,5° southward about an axis of SS-4. The section passes through the accelerator plane and is constructed in the same rocks as the main accelerator using the mastered technologies. The channel goes out from the outside of the proton tunnel and passes in parallel with the circle tunnel at some distance, which is determined by the drifting conditions and also by the requirements of radiation protection for the working accelerator.

In order to transport the beam on this section one can use the already mastered magnet-optical elements, vacuum system and power sources of UNK-1. It is necessary to place 156 standard dipole and 26 quadrupole magnets, which are supplied in succession from the same power supply. In this case the section length is 1200 m. The tunnel construction and ground engineering equipment: magnets water-cooling, ventilation, etc. can be made by analogy with already built injection channel passing from U-70 to UNK.

The second section of the transportation channel provides the beam rotation in the vertical plane by 9.7°. This section will pass through a soil with subterranean waters, and this fact will make the drifting more difficult, that's why its length should be minimized.

The following variants of constructing the section of rotation in the vertical plane are possible:

1. If it is planned to use the magnets of UNK-1, then the quantity of dipoles is 60, quadrupoles - 10. The section length will be 450 m and the deepening of the section end relative to the orbit plane will be 92 m.

2. When using the special magnets of usual type ("warm") with the maximal field 2 T, the section length will be decreased up to 270 m and the drifting - up to 44 m, correspondingly. Quantity of dipoles will be 30, the quadrupoles may be the same as those used for UNK-1.

3. When using the superconducting magnets of UNK-2 with the field 5 T one can shorten the section length to 120 m and the drifting to 19 m as well, however, the channel construction will abruptly be complicated due to the necessity to place the cryogenic equipment (refrigerator) in the underground buildings.

With account for the total length of the deepened tunnel section containing the space for the target placing and the decay channel with the total length of about 500 m, it is reasonable to accept the second variant, and in this case the technological aspects of the channel and its providing can be solved on the base of the developed equipment.

The requirements on the current instability of power sources are the same as for UNK-1 (about $1 \cdot 10^{-4}$) [22].

7.4. The neutrino target station (NTS)

The neutrino channel itself contains the target station, the focusing system, the decay section and the hadron beam absorber (Fig.11). The target station, the focusing system and a necessary shield are situated in a target hall or in a tunnel broadening, whose parameters provide stable maintenance of the equipment with account for the high level of caused activity.

The decay section of the neutrino channel consists of the broadening vacuum chamber 470 m long. At the end of the decay section there is an absorber for noninteracted protons and secondary particles in the target. The total length of the neutrino channel is 500 m.

NTS is situated in the trace section of the proton beam after rotating the beam in the Gran Sasso direction. This direction has the slope angle 9.7° about the horizontal plane. The depth of a trace from the earth surface near the NTS displacement is 100 m. The general arrangement of NTS, preceding and the subsequent focusing optics and the radiation shield elements is determined by the condition of forming the neutrino beams with the wide spectrum. The parameters of the initial proton beam, which is thrown on the target, are the following:

The energy	– 600 GeV
The duration of acceleration cycle	– 120 s
The duration of accelerated protons circulation in an accelerator (duration of plateau of maximal magnet field)	– 20 s
The intensity per cycle	– $3 \cdot 10^{14}$ protons
The fast multiturn extraction (on the magnet field plateau)	
The duration of the separated extraction	– 70 μs
The duration of the pause between two extractions	– 2 s.

The main target requirements are:

1. The use of a material with the high yield of secondary particles per one falling proton.

2. The geometric beam size must correspond to two nuclear interaction lengths of protons and must not exceed 2 m.

3. The long-term working period without destructions and efficiency losses not less than 10^5 cycles at the maximal extracted protons intensity.

4. The possibility to work in the air medium.

The essential factor, which determines the design and the working regime of the target section (and NTS as a whole), is a sufficient macroscopic radiation heating of equipment, situated under the direct influence of a proton beam and secondary particles "torch", which escapes from the target. Taking into account these requirements and working conditions the chosen material for the target is beryllium, however its use is connected with certain limitations in the working regime of the beam. That is the absorber heating must not exceed the allowed limit, the number of proton beam spills per cycle must be not less than 3 (with the uniform time distribution per a plateau of a magnet field). In this case the allowed diameter of the proton beam at the target is 1 cm, which gives a possibility to obtain a sufficiently high efficiency of subsequent focusing optics. In the case of one turn spill the allowed beam diameter, at which the neutrino flux decreases 3 times, is $\sim$ 6 cm.

The target cooling is carried out through the side surface. The target is placed in a hermetic container, cooled by water. The target cross-sections are optimized from the conditions of the heat elimination and are in a range of 2-4 cm. The power of the energy deposition in the target section is 1.5 kW.

The target section and adjoining facilities of focusing optics are surrounded by the combined radiation shield made of iron and concrete blocks. The thickness of the iron shield is 1 m at the front butt-end of NTS (from the side of the proton beam entrance), 1-1.5 m at sides and 5 m at the back butt-end. The thickness of the concrete shield is 0.5 m. In order to make NTS maintenance more comfortable, the expanding shield is used. The mass of the iron shield of the target block and the focusing facility elements is 1300 t, and that of the concrete is 460 t.

NTS is situated in the "gap" of the ion conductor of original and secondary beams (in atmosphere). The "hot" (internal, near target) zone is force ventilated in order to extract the radionuclides and cool the neighboring shield blocks. NTS is equipped with the facilities to align and control beams parameters and conditions of the main elements and power sources.

In order to arrange facilities and equipment of NTS and focusing optics, the 45 m tunnel near the station is widened up to 10 m (Fig.12) or the parallel service tunnel is organized along the mentioned length. The beam zone and the service tunnel are separated by the additional concrete shield 2-3 m thick (or soil shield - 4-5 m). Just near the equipment zone the vertical shaft for transporting the operating staff and loads is situated.

7.5. The focusing system to form neutrino beam with the wide energetic spectrum

Fig.12 shows the approximate arrangement of underground buildings for the location of the target station and focusing system on the base of axially-symmetrical current shells (parabolic lenses).

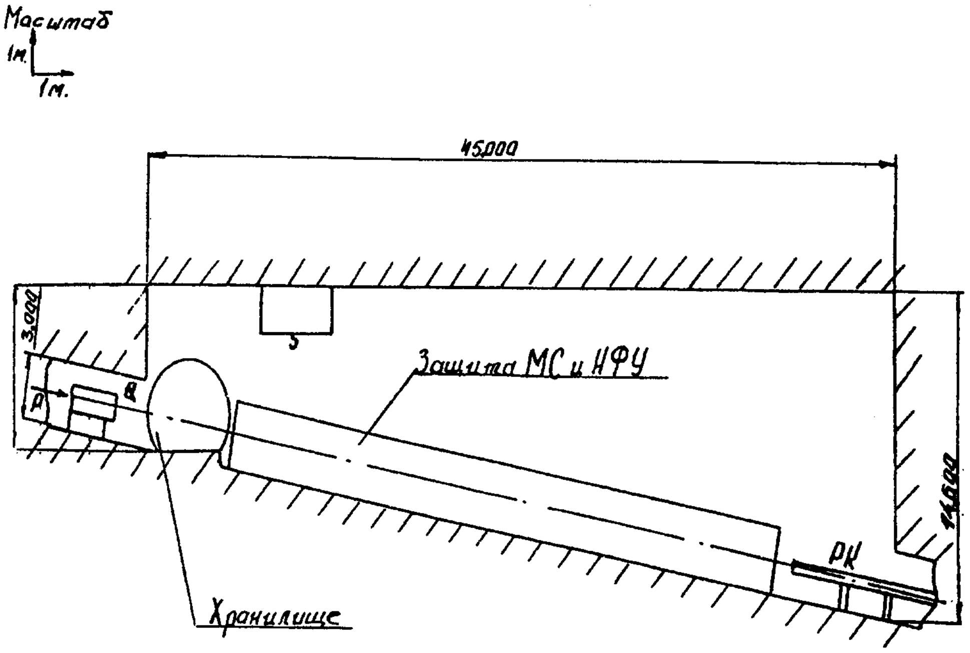

Fig. 12. The layout of the underground construction (Hall M3).

Fig.13 represents the target hall arrangement with the focusing system using 9 radioresistant quadrupole lenses QBR, proposed for the UNK experimental base. Technical parameters of quadrupole lenses are given in Table 5.

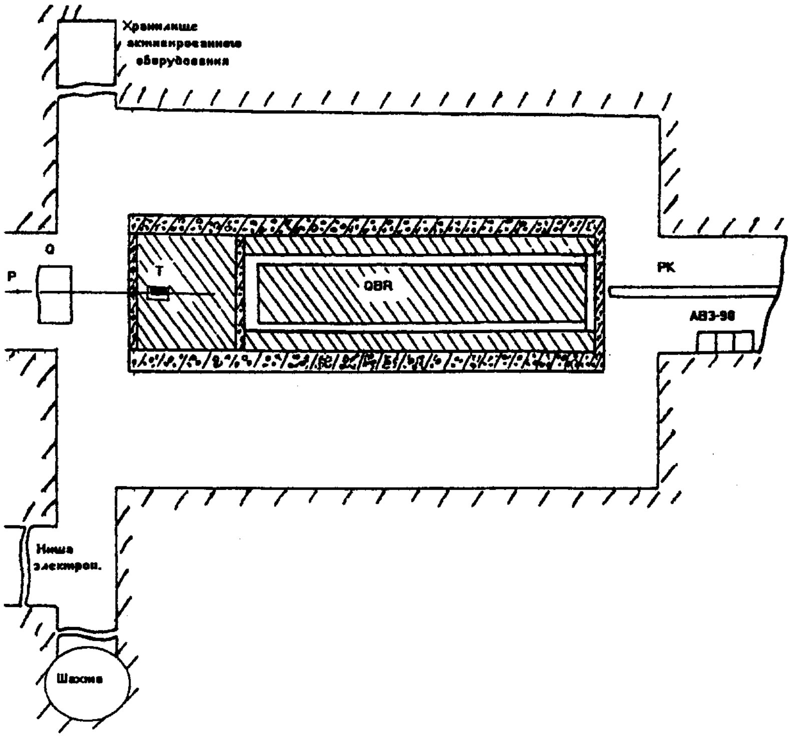

Fig. 13. NFF (neutrino focusing facility) with QBR (quadrupole lenses).

Table 5. Technical parameters of quadrupole lenses

Induction gradient (tesla/m)	15
Aperture diameter (mm)	140
Length of pole tip (mm)	2000
Current amplitude (A)	950
Effective current (A)	595
Voltage drop (V)	155
Cooling water pressure (MPa)	2
Mass (kg)	15000

It is necessary to foresee water cooling under the pressure of 2 MPa to the target hall. For supplying 9 QBR (155, 950 V) it is proposed to use developed stabilized power supplies IST2, situated in the technological building on the earth surface.

7.6. Main technical characteristics of the vacuum chamber of the decay base

The vacuum chamber of the neutrino complex is proposed for neutrino beams forming. It is the extended vacuum volume, which has in the initial part the cylindrical ion conductor 140 mm in diameter and 25 m long (in lenses). Then the stepped widened vacuum chamber of a decay base follows. It is a construction from 200 to 2000 mm in diameter. The total length of the decay chamber is 470 m, made of stainless – non-corrosive steel 12X18N10T. Due to deficiency of a stainless steel it is possible to use for the chamber construction the black rolled metal with an anticorrosive covering of the external surface. The length of the initial section of the decay chamber with 200 mm diameter must be 25 m, then the diameter must be increased step by step every 25 m to 500 m, and further every 25 m to 700 m. The diameters of the following sections must be increased by 200 mm every 50 m.

The thickness of chamber walls with the diameter from 200 to 500 mm is equal to 4 mm, from 1500 to 2000 mm is 5 mm. Beginning with the diameter of 1000 mm and larger the chamber construction due to strength conditions must be already with ribs, which are situated at 1500 mm step.

The chamber mass is supposed to be around 80 t, including hermetic covers and constructions, which close the chamber at butt-ends.

The working pressure in the chamber is $P = 1.0 \div 0.1$ Torr.

The pumping of the chamber to get the working pressure is carried out by four vacuum units on the base of mechanical pumps AV-90, which can be placed in the initial part of the stepped vacuum chamber. The unit must consist of the blocking vacuum gauge and the manometer sensor. All pumping units must be situated in a separate section or in a separate room, shielded from the radiation. For pumping the ion conductor of the neutrino focusing facility with 140 mm in diameter and also for adjustment works at the beginning of section, it is necessary to use the pumping unit on the base of pump NB3-20 or AV3-20D with the corresponding measuring instrument.

The chamber is supposed to be placed in the underground gallery, where it must be mounted directly of separate welded sections.

It is necessary to foresee the pumps supplying of cooling water and centralized system of gas removing.

The range of temperature oscillations in the gallery is 6-20°. The humidity is not higher than 90%.

7.7. Beam absorber (BA)

The absorber of a non-interacted proton beam and secondary particles is situated in a special room at the end of the decay section tunnel (see section "Building part").

Tentatively, the BA consists of the graphite kernel 300 mm in diameter and 5 m long, surrounded by the iron shell with sizes $\sim 2,5 \times 2,5 \times 8$ m. The iron is supposed to be covered with the concrete layer 0.5 m thick.

The iron mass of BA is 470 t.

The concrete mass is 100 t.

The BA construction provides the radiation at sides of tunnels, which is not higher than normal.

7.8. Beams monitoring

This system is used to provide the channel adjustment and its systems and control the stability of the given parameters during physical experiments. The main requirements are: the control of the secondary beam direction stability with a resolution not less than 0.05 mrad. It is necessary to control both secondary and initial proton beams in the target. Besides the direction, the essential parameters are also the secondary beam divergence (and its stability) and the intensity of the secondary and initial beams.

The system consists of different types of detectors, analogue electronics, placed directly near the detectors, digital electronics for a signal processing and electronics responsible for the connection with PC.

In order to measure the proton beam intensity it is proposed to use the current transformer and monitors on the basis of secondary emission, and for the secondary beam – the ionizing chambers.

For measuring the position, profile and divergency of proton and secondary beams it is supposed to use wire or band detectors based on secondary emission and ionizing type detectors.

Detectors are supposed to be placed inside the ion conductor in separate sections, independent vacuum boxes or in atmosphere.

It is also necessary to measure the profile and the absolute value of muon flux, for which purpose the head part of filter (behind decay channel) must be made of steel (the beam length is 5 m, transverse sizes are 4×4 m^2).

Behind the filter the coordinate and integrating muon detectors are situated.

8. Construction facilities

Construction complex to provide the neutrino experiment at the Gran Sasso facility consists of the following constructions (Fig.11):

- the building for engineering service (by analogy with b.1017 of U-600 project); the tunnel of the proton beam transport from U-600;
- the target hall (TH) with the tunnel to shaft №1, the niche for electronics and the temporary storage of an activated equipment (Fig.14,15);
- the surface building for an engineering service (by analogy with b.1023 of the U-600 project);
- the tunnel of the vacuum chamber in a decay base;
- the room for the beam absorber (BA) with the tunnel to shaft №2;
- the ventilation center (by analogy with b.1553 of the U-600 project);

- the experimental hall (EH) with tunnels to shafts №3 and №4;
- the surface building of the engineering service with shafts №3 and №4 (by analogy with b.1453 of the U-600 project).

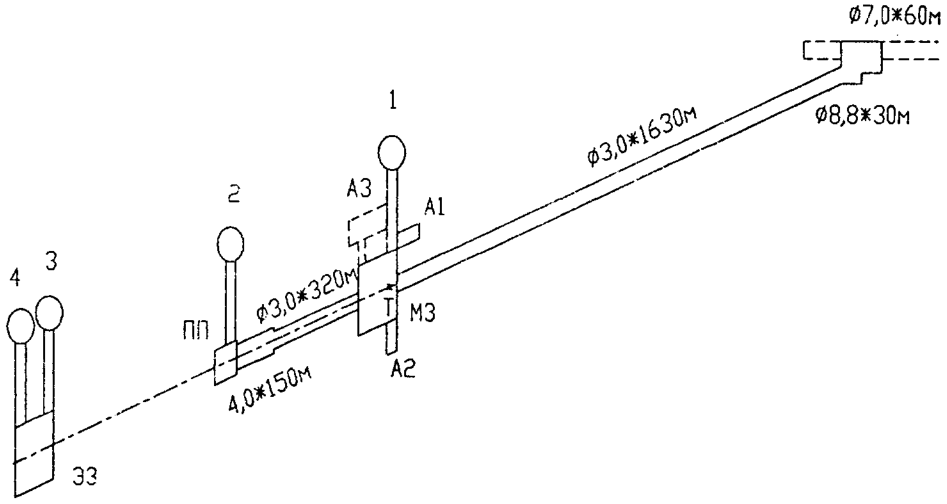

Fig. 14. The neutrino complex profile towards Gran Sasso.

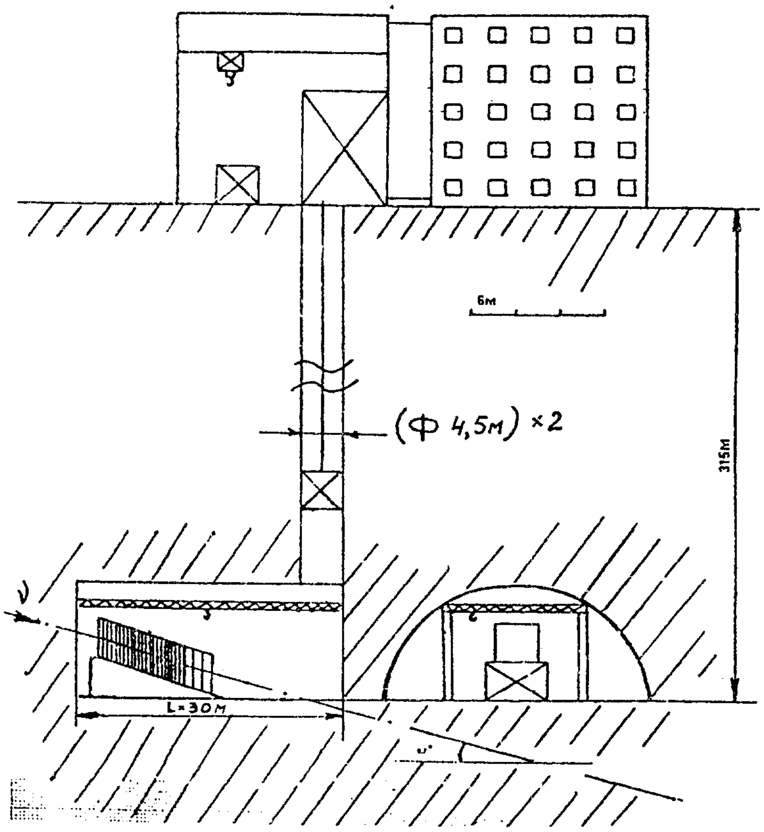

Fig. 15. The schematics of the nearby neutrino detector.

Beginning with the coordinate U=78173 m (200 m to the b.1023) the tunnel ∅ 5.1 m of a proton channel of the U-600 experimental base is widened up to ∅ 7.0 m at the length 60 m and then to ∅ 8.8 m at the length 30 m. The tunnel ∅ 8.8 m is divided into two: the proton channel ∅ 5.1 m (the existing U-600 project) and the tunnel of a proton beam transporting towards Gran Sasso ∅ 3.0 m, 1650 m long. In the region of a tunnel widening the engineering service building is placed by analogy with that of b.1017 of the U-600 project, which is proposed for placing the common technological equipment (ventilation, water cooling) and magnets power supplies of magnets.

The tunnel ∅ 3.0 m adjoins the target hall (TH), which is built with the slanting floor (the slope angle is 10°) and a horizontal vault. The height to the vault at the beginning of a hall is 7 m, at the end is 14.6 m, the hall width is 10 m, the length is 45 m (Fig.14). For servicing and mounting the equipment the bridge crane of 15 t carrying capacity is foreseen. At the beginning of the hall there is a storage for the temporary storing of the activated equipment ∅ 5.1 m, 15 m long and the approaching tunnel 4.0×4.0 m towards shaft №1 is 10 m long. The shaft depth is 100 m, ∅ 7 m (Fig.11,15).

Behind the target hall the decay channel is situated, which consists of two sections 3.0×3.0 m, 320 m long and 4.0×4.0 m, 150 m long. Then there goes the beam absorber room (BA) with a slanting floor and a horizontal vault. The height at the beginning of BA room is 7 m, at the end 9.4 m, BA room width is 7 m, the length – 14 m (Fig.14).

For mounting the equipment in the BA room the bridge crane of the 5 T carrying capacity is placed. After assembling the BA crane can be dismounted. At the beginning of the BA room there is the approaching tunnel 4.0×4.0 m, 10 m long towards shaft №2, ∅ 5.5 m, 170 m deep. This shaft is necessary because of technology conditions.

At the 1000 m distance from BA the experimental hall (EH) (Fig.9,11), whose sizes are as those for TH, is situated. At the beginning of EH it is supposed to place the approaching tunnel 4.0×4.0 m, 10 m long towards shaft №3 ∅ 7.0 m, 315 m deep. At the end of EH the same approaching tunnel is supposed to be with a shaft due to safety conditions.

In accordance with two variants of a neutrino beam focusing different compositions of TH are possible.

In the first case (focused by a system of 9 quadroupole lenses) power supplies of a magnet equipment of a focusing facility are situated in the surface building of an engineering service above shaft №1. Building sizes are similar to those of the b.1023 for the existing project of the experimental base (fig.6).

The second version (focused by coaxial current shells) foresees, besides a surface building, the underground service tunnel 6.0×5.0 m, 50 m long, situated horizontally along TH with the approaching tunnel 3.0×3.0 m, 4 m long.

The service tunnel serves for placing the equipment of a neutrino focusing facility pulse supply. In the service tunnel the hanging crane of a 3 t carrying capacity (Fig.7) is proposed.

Above shaft №2 the surface building for ventilation service, identically to b.1553 of the U-600 project, is situated.

Due to the great difficulty in mounting slanting channels and halls (the 10° slope angle) it is necessary to develop special facilities and a mounting technology.

8.1. The zone of the nearby detector

The buildings complex of the neutrino detector consists of the underground hall (hall EH), transport and communication shafts and the laboratory surface building №3, identically to b.97 of the U-600 project.

The underground hall EH is proposed for planned here the nearbly neutrino detector and the auxiliary equipment for its mounting, tuning and exploitation. The hall is situated at the 315 m depth. The hall has an arc construction (Fig.9), its sizes are R=15 m, L=60 m. The allowed floor capacity 10 t/m^2 in the detector zone. The hall is provided with a beam-crane with the carrying capacity 10 t, the maximal height of a load from the floor is 10 m.

It is needed to foresee:

1.The engineering service:

- the electrical energy supply,
- the ventilation,
- the gas supply,
- the water supply,
- the system of fire alarm and extinguishing,
- the illumination in accordance with standards for underground buildings.

2.Other services:

- the cable channel for the information read out,
- the dose control equipment,
- the telephone,
- the loud communication with surface buildings,
- the gas analyzation system,
- the ventilation in accordance with standards for underground buildings.

8.2. Building №3

Building №3 incorporates the laboratory and technological blocks. Laboratory building serves for placing:

– the systems of control and information read out from the neutrino detector;
– the test bench;
– the computational center;
– the express – workshops;
– the service personnel;
– the scientists and mission personnel.

Technological building is intended for:

– placing the lift equipment of shafts;
– transporting and mounting the big sizes equipment of the neutrino detector;

- placing the equipment for the detector engineering service;
- storing the compressed gases;
- for mounting the standard tanks for the liquid nitrogen storing.

8.3. Transport and communication shafts

The shafts are used for transporting the equipment and personnel to experimental buildings, placing the energy supply lines and carrying out the engineering service of the channel equipment and the nearby neutrino detector. The diameter of each shaft is 4.5 m, the depth is 315 m. The shafts are equipped with the load lift equipment, the crane and alarm safety systems due to standards for underground buildings.

Summary

The study of neutrino oscillations with long-baseline neutrino beams is one of the most important problems in the program of physical investigations at the UNK-1 accelerator. A possibility to direct the neutrino beam to different detectors, used for similar investigations, such as ICARUS, MACRO, LVD, NESTOR, BAIKAL, will allow one to choose optimal experiment configuration both for the efficiency of statistics gaining and for the most informative data interpretation. Analogous investigations with long-baseline neutrino beams at detectors, situated at Gran Sasso, have been also planned for the CERN accelerator, that will allow one to use at most the potentials of detectors. At present it is clear that only rich statistics, obtained in experiments with long-baseline neutrinos, will answer the fundamental question of the neutrino oscillations existence.

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Received February 10, 1995

Cost estimate of creating the long baseline neutrino beam

Table 6. Equipment Cost Estimate

Equipment	Quantity	Cost of the unit in prices of 1994 (millions of rubles)	Cost in prices of 1994 (millions of rubles)
1. Optical magnet equipment QBR	9	22	198
2. Power source YST2 660/1000	4	105	420
3. Biologic shielding NFU + PP (iron)	1270 t		635
4. Vacuum system + vacuum chamber of decay base	80 t		2500 (steel) 1500 (ferrous)
5. Capacity equipment	7 cranes		1200
6. Cables	10 km	12 millions/km	120
7. Target station (with the biologic shield and engineer. providing system)	1		2500
8. Control system	not est.		
9. General engineer. equipment (10%)			760
Subtotal			8330
Elements of the beam transporting towards target	252		5040
Total			13370

Table 7. Neutrino Detector Equipment Cost Estimation

Equipment	Cost in prices of 1994 (millions of rubles)
1. Steel plates	200
2. Magnetizing system	800
3. Electronics of information read out, high voltage and gas system	10000
4. Scintillation plastics	200
5. Electronics scint. counters	1200
6. Building and mounting works	400
Total	12800

Table 8. Cost Estimation of the building and mounting of the underground construction of the experiment

	Construction	Cost in prices of 1991 (thousands of rubles)
1.	Vertical barrel ∅ 7 m; H=100 m;12 x 100	1200
2.	Shaft towards the barrel; 4×4×10 m;8x10	80
3.	Branching section:	
	– tunnel ∅ 7 m; L=60 m; -8x60	480
	– tunnel ∅ 8.8 m; L=30 m; -12x30	360
4.	Linear tunnel L=1560 m,∅ 3 m (without spec. meth.)	12480
4a.	Ventillation shafts, 2	150
5.	Target hall 10x11x457 m; (by analogy with hall SS-3)	8000
6.	Niche ∅ 5.1 m; L=12 m	96
7.	Storehouse ∅ 5.1 m;L=15 m	120
8.	Service channel 6×5×50 and approaching shaft	432
9	Beam absorber room	2500
10.	Vertical barrel ∅ 5.5 m;ю=170 m (spec. method)	4250
11.	Tunnel towards the barrel 4x4x10 (spec. meth.)	200
12.	Linear tunnel from M3 to BA, L=470 m (spec. method)	940
13.	Vertical barrel ∅ 4 m, ю=315 m (spec. method)	18900
14.	Approaching tunnels 4x4x10 (spec. method)	0400
15.	Experimental hall 10x11x450 (spec. method)	20000
	Subtotal	70440
16.	Temporal buildings and constructions (10%)	7050
	Total with temp. buildings	77500
	Total with coefficient with account for insufficiency in engineering-geological data (K=1.8)	140000

Table 9. Cost Estimation of SMR for Surface Buildings

Construction	Cost in prices of 1991 (thousands of rubles)
1. EEB over shaft N1 (analogously to b.1023)	1747
2. EEB over shaft N2 (analogously to b.1553)	45
3. EEB over shaft N3 (analogously to b.1453)	774
4. EEB at ground 1023 (analogously to b.1017)	2438
5. Roads and grounds 45 km	1900
Total	6904

Engineering Nets for Providing EEB (Engineering Equipment Buildings) and Underground Works.

1. Electricity	190
2. Cabel lines of special fire extinguishing	70
3. Communication and signal lines	10
4. Sewage pump stations (2)	50
5. Water pipe (2)	120
6. Heating system	170
7. Sewage and drainpipe	100
Total	710

Technological supply: – thermostatic system – conditioning system – safety system – carrying transport equipment 15% of Section I	80000×0.15=12000.
Total in Section II	19610
Temp. buildings and constructions in Section II	2000

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Оригинал-макет подготовлен с помощью системы LaTeX.
Редактор Е.Н.Горина. Технический редактор Н.В.Орлова.

Подписано к печати 13.02.1995 г. Формат 60 × 84/8. Офсетная печать.
Печ.л. 4,12. Уч.-изд.л. 3,16. Тираж 120. Заказ 307. Индекс 3649.
ЛР №020498 06.04.1992 г.

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142284, Протвино Московской обл.

Индекс 3649

ПРЕПРИНТ 95-18, ИФВЭ, 1995
