DOI: 10.15415/jnp.2015.31009

Sensitivity Studies Using Globes

JYOTI TRIPATHI *, VIPIN BHATNAGAR, ASHOK KUMAR AND J.S. SHAHI

Department of physics, Panjab University, Chandigarh-160014

***Email: tjyoti@fnal.gov**

Received: April 9, 2015 | Revised: June 18 13, 2015 | Accepted: July 14, 2015

Published online: August 03, 2015

Abstract: Neutrino oscillation occurs if neutrinos have masses and if they mix among each other. This phenomenon would be in close analogy to the experimentally observed mixing in quark sector. Neutrino oscillations are therefore very interesting in the context of elementary particle physics. Neutrino oscillation in matter is probably the reason for the observed deficit of solar neutrino flux .The search for neutrino oscillation is the only way to investigate even for very small difference of neutrino masses. The evidence of small but non vanishing neutrino masses represent one of the few clear indications of the physics beyond standard model. The findings of nonzero neutrino masses by Super-Kamiokande in 1998 triggered a huge interest of experimentalists in neutrino physics.

In the present article after discussing the theoretical background concerning massive neutrinos and their status in standard model, latest important long baseline experiments dealing with neutrino oscillations have been discussed. It has been tried to show the important link between the physics behind neutrino oscillation and the software used (GloBES).

1. INTRODUCTION

The neutrino was postulated by Pauli in 1930 in order to conserve energy, momentum and angular momentum in beta decay. The neutrino is a neutral weakly interacting particle. Neutrinos are created in certain type of radioactive decay or nuclear reactions that take place in sun or in nuclear reactors.

Neutrinos are also produced when cosmic rays hit the nuclei in upper atmosphere. Neutrinos are affected by weak subatomic forces of much short range and gravity which is relatively very weak on sub-atomic scale that is why a typical neutrino passes through matter unimpeded. As per standard model neutrinos are massless because if a left handed neutrino collides with Higgs bosons it would have to become right handed, since no such state

Journal of Nuclear Physics, Material Sciences, Radiation and Applications
Vol. 3, No. 1
August 2015
pp. 75–86

of neutrinos exist, the left handed neutrino is unable to interact with the higgs boson and therefore do not acquire any mass. In this way, massless neutrinos go hand in hand with the absence of right handed neutrinos in standard model. Neutrino has three different flavours-electron, muon and tau and each type is associated with its antiparticle called antineutrino.

Neutrinos are among the most abundant particles in the universe. Scientists have build detectors underground, underwater to detect these particles. Since neutrinos hardly interact with matter so only very sophisticated experiments can catch and measure the properties of neutrino. The neutrino seems to have a remarkable property: its spin is always oriented in the direction opposite to its velocity (it is said to be of (left helicity) the anti-neutrino is always of right helicity (spin in the same direction as the velocity).

2. NEUTRINO OSCILLATIONS

Neutrinos have this very special property that their flavor eigenstates do not coincide with their mass eigenstates. Flavour states can be expressed in the mass-eigenstates system and vice versa. Consequently, for a given energy the mass states propagate at different velocities and the flavour states change with time. This effect is known as oscillations. It has been discovered from experiments deep underground in extreme darkness with many thousands of tonnes of water housed in mines that neutrinos have nonzero mass and the leptons mix. The neutrinos have masses means there is a spectrum of mass eigenstates (υi) each with a slightly different mass .Mixing simply means that in the W+ decaying to the particular charge anti-lepton the accompanying neutrino's mass eigen-state is not always the same υ_i but can be any of the different υ_i. The neutrino state emitted in the W decay together with the charge anti-lepton is $|\upsilon\alpha\rangle = \Sigma U^*\alpha_i|\upsilon_i\rangle$.

This superposition of mass eigenstates is called neutrino of flavor α. So a neutrino born as an electron neutrino will be a mixture of electron, muon and tau neutrino after travelling some distance. The idea of neutrino oscillation was put forward by Bruno Pontecorvo in 1957 which made the foundation for the qualitative theory of neutrino flavour oscillation developed by Maki, Nakagawa and Sakata in 1967. A simple relation gives the probability of oscillation between two flavors of neutrino $P(\upsilon_1 \rightarrow \upsilon_2) = \sin^2 2\theta . \sin^2(\Delta m^2 L/4E)$

3. EXPERIMENT LOOKING FOR NEUTRINO OSCILLATION

Neutrino oscillation between neutrino families could help to explain the deficit observed in the solar neutrino flux and could be a good experimental tagging of the fact that neutrinos are massive. Many experiments near nuclear plants or at particles accelerators have tried to explore this way since more than 20 years.

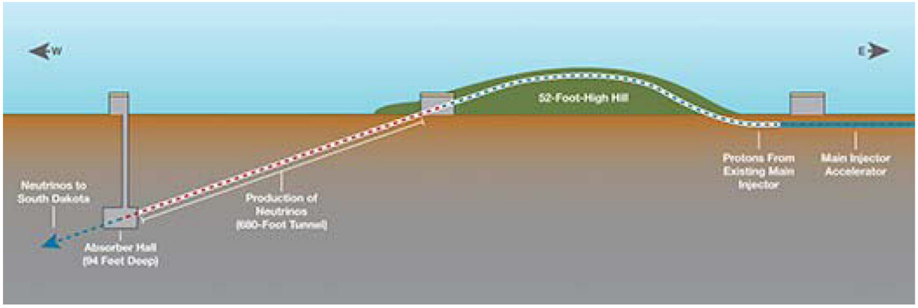


Figure 1: Fermilab creates neutrinos using a high-energy proton beam and plans to funnel them 900 miles to a detector in South Dakota's Sanford Underground Research Facility.

But since 1996, more and more results in favour of neutrino oscillation appear. Some of the experiments are discussed NOvA and LBNE: Goal is to observe the oscillation of muon neutrino to electron neutrino and accomplish three things – measurement of the mixing angle θ_{13}, measurement of CP violating phase δcp and determination of neutrino mass hierarchy. NOvA will be an order of magnitude more sensitive to θ_{13} than any previous detector. Both will determine it by searching for muon neutrino to electron neutrino oscillation in Fermilab's NuMI beam.

For detecting neutrinos, NOvA uses near detector (at Fermilab) and Far detector (Northern Minnesota) using liquid scintillator as the detecting material. The far detector is comparatively much more massive than the near detector. No tunnel is needed to steer the beam of neutrinos.

4. LBNE

This experiment will send the world's highest energy neutrino beam through the earth's mantle to a large Detector, a multi-kiloton volume of target material installed there to record the interactions between neutrinos and target materials with a baseline of 1300 km. Fermilab is the site of neutrino's beam line for LBNE and the Sanford Underground Research laboratory is selected as the site for the massive far detector (house of the far detector) in Lead south Dakota. It would steer protons from Fermilab's Main Injector accelerator up a small hill and then the beam will be pointed into the ground towards the Sanford lab.

5. LBNE NEAR DETECTOR AND STT

LBNE plans to use straw tube based fine grained tracker. The FGT has excellent position and angular resolutions due to its lower-density (~0.1 g/cm^2) and high precision Straw tube tracker. This high resolution is important

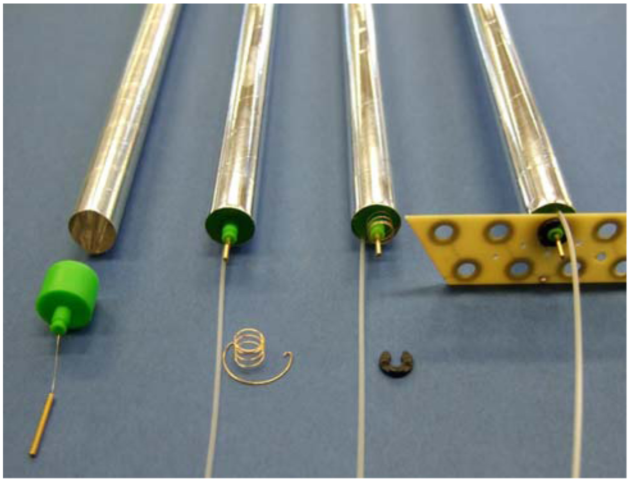


Figure 2: Straw tubes in PANDA experiment.

for determining the neutrino whether the neutrino interaction occurs in the water or argon target. The proposed $2.5 \times 2.5 \times 4\ m^3$ tracker will be positioned inside a dipole magnet with magnetic field, B = 0.4 T for particle tracking. The nominal fiducial volume corresponds to 2.5 tons of mass.

Straw tubes are the basic detecting elements of STT. Straws are gas filled cylindrical tubes with a conductive inner layer as cathode and a thin wire acting as anode. An electric field between the wire and the outer conductor applied separates electrons and positive ions produced by the charge particles along its trajectory through the gas volume. The specific energy loss (dE/dx) of the charged particle in the straw gas volume can be used for particle identification. The PID information from STT is needed to separate the charged particles protons, kaons and pions.

6. GENERAL LONG BASELINE EXPERIMENT SIMULATOR

The GLoBES software package is a modern experiment simulation and analysis tool for highly accurate beam and detector simulation. GLoBES is used to characterize the sensitivity of the parameters like δcp and θ_{13} for a particular experiment. It simulates neutrino beam as it travels from source to detector. The simulator computes oscillation probabilities and corresponding event rates for the channels that are set for observation in the simulated experiment. It also provides powerful means to analyze correlation and degeneracy for several combinations of several experiments.

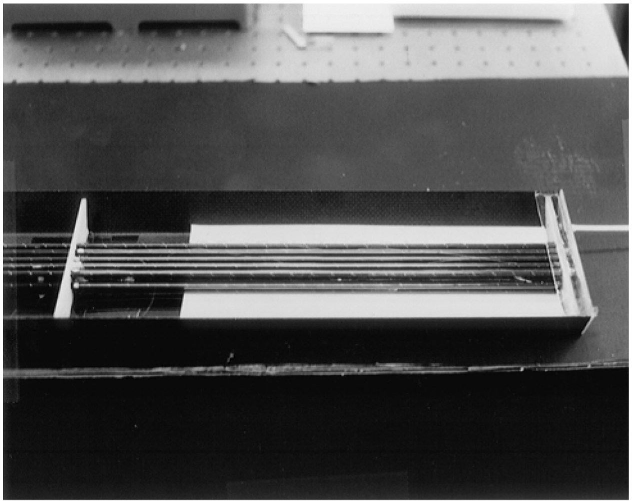


Figure 3: Straw tube assembled in a chamber GloBES.

7. CONCEPT OF GLOBES

This software simulates the short and long baseline neutrino oscillation experiment. GLoBES consists of AEDL (Abstract Experimental Definition language) to describe the experiment. AEDL tries to describe large number of experiments using limited parameters and a C library to process the experiment information and calculate the oscillation probabilities and $\chi 2$ values. GLoBES allows to simulate neutrino experiments with stationary neutrino source where each experiment is allowed to have only one neutrino source. With the C library, delta chi square of all defined oscillation channels of an experiment or a combination of an experiment can be obtained. GLoBES includes the simulation of neutrino oscillations in matter with arbitrary matter density profiles.

8. CALCULATION OF OSCILLATION PROBABILITY

The description of a neutrino experiment can be split into three parts- Source oscillation and detection. The matter density profile is divided into layers of constant matter density. For each of these layers the Hamiltonian in matter is diagnolized in order to propagate the neutrino transition amplitudes. Transition probability is obtained as the square of neutrino transition amplitude. The general properties of a detector are much more complicated but certain assumptions are made to simplify it a) Basic assumption in building an abstract detector is its linearity i.e. the two neutrino events do not interfere with each other. b) All

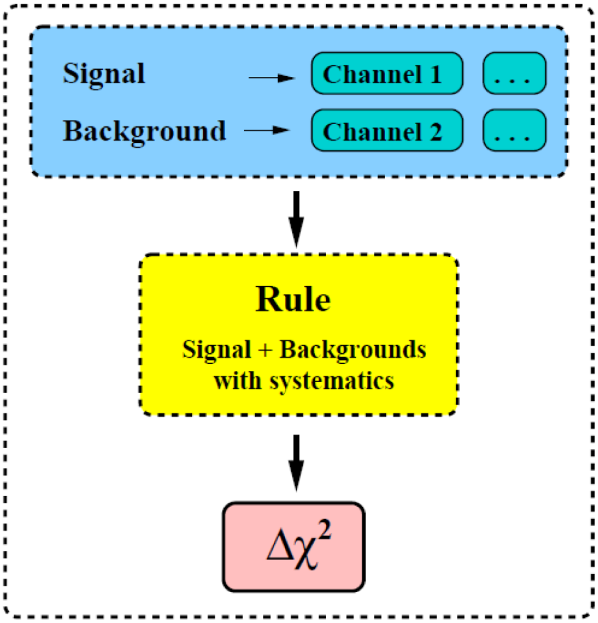


Figure 4:

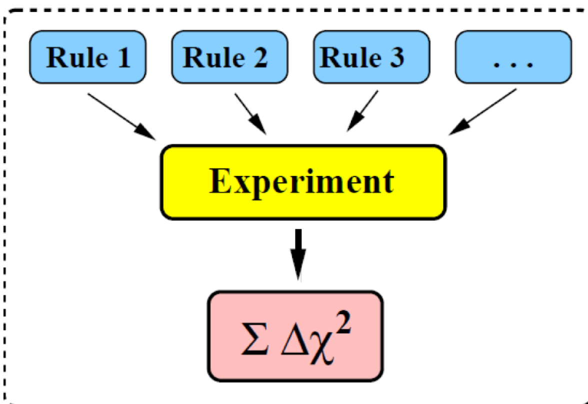


Figure 5:

information on the oscillation particles is given by reconstructed flavour and energy of a neutrino event. Reconstructed neutrino energy and reconstructed neutrino flavour are the only observables in GLoBES.

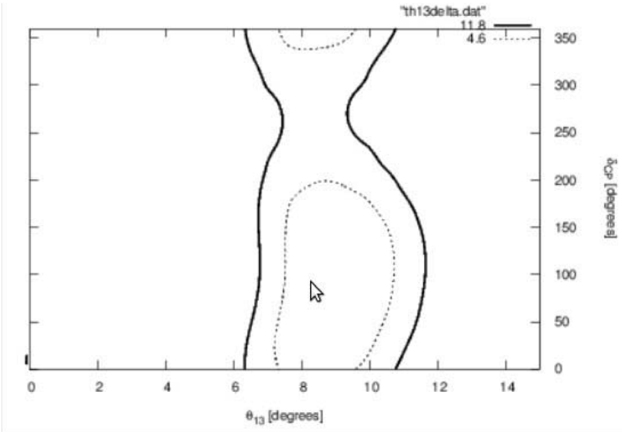
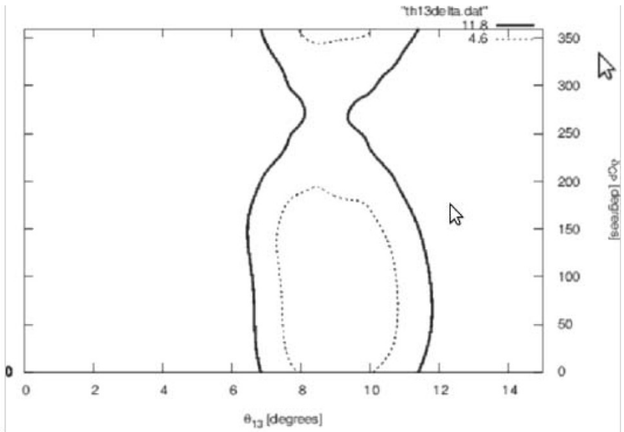


Figure 6:

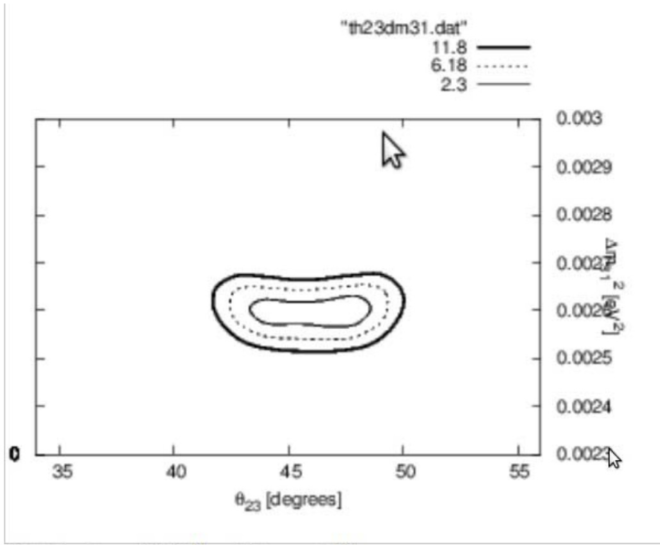


Plot for inverted mass hierarchy

Figure 7:

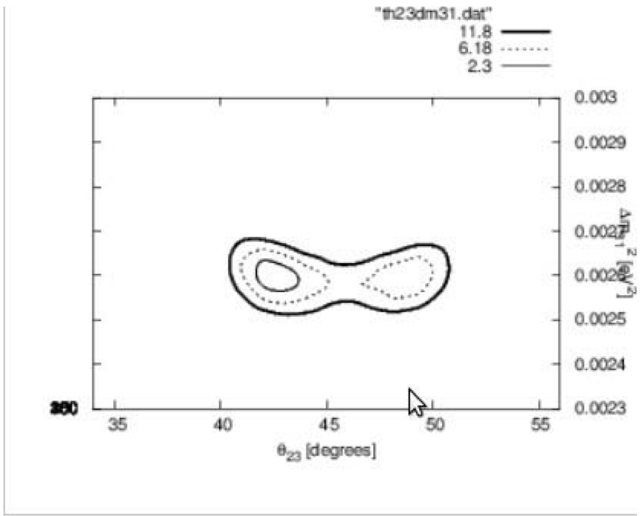
8.1 Abstract experiment definition language

AEDL is a special syntax developed for the description of experiments in GLoBES, represented by simple text files. Core part of AEDL are the following constructions CHANNEL – A channel represents the link between oscillation physics and detection properties for a specific oscillation pattern .Channels form the building block of rules. **The following two blocks show the general concept of a rule and an experiment.**



Plot for Θ_{23} = 47.50^0 and δcp = 0.0^0

Figure 8:



Plot for Θ_{23} = 42.50^0 and δcp =0.0^0

Figure 9:

RULE- it consists of one or more signal and background oscillation channels. The event number from these channels is added before $\Delta\chi^2$ is calculated.

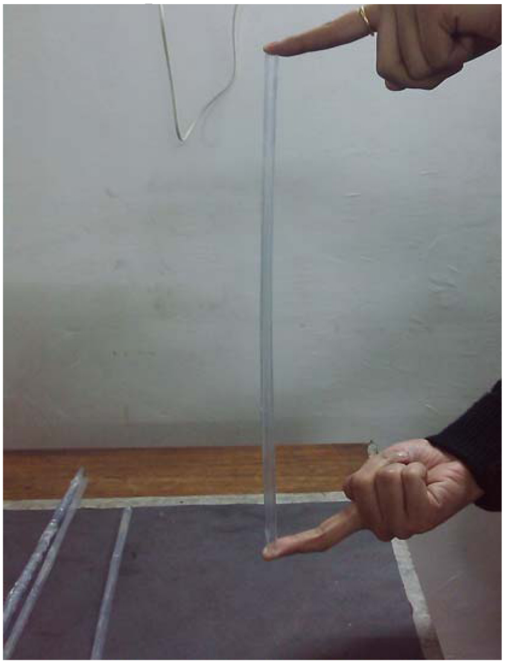


Figure 10: The above figures show the fabrication of straws using ordinary plastic.

EXPERIMENT – an experiment is a combination of one or more rules which may correspond to different appearance and disappearance channels, neutrino and antineutrino operations modes, etc.

CORRELATION PLOTS OBTAINED USING GLoBES 3.0 – The plots have been obtained by setting the target mass at 15kt and a baseline of 812 km. Time taken is 3 year for neutrino and 3 year for antineutrino running Beam power is 0.7 mw and energy range used is 0.5 to 3.5 GeV.

9. CONCLUSION

In summary, GLoBES provides powerful tools to do a full three flavour analysis of future long baseline and reactor experiments including systematic and correlations. In addition the abstract experimental definition language allows defining experiment at an abstract level in a highly accurate way.

The major strength of GLoBES is:

- · Its ability to define new experiments and take into account the full multi parameter correlation.
- The possibilities to include external input and matter densities uncertainties

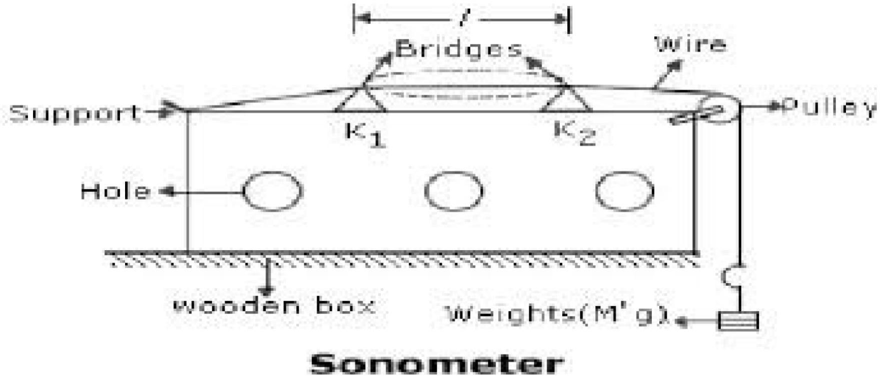


Figure 11:

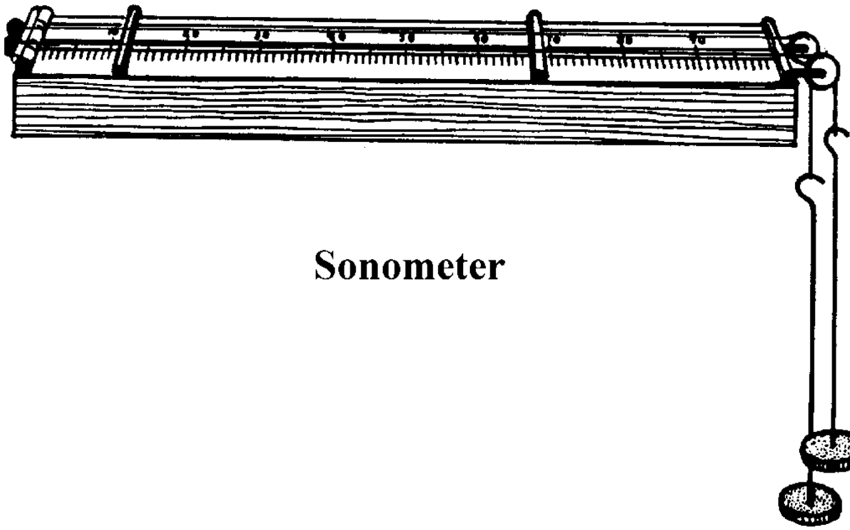


Figure 12: Above figures show the schematic of the wire tension measurement using sonometer and thin wire.

GLoBES has provided a framework for estimating sensitivities to non-zero theta13, CP violation and mass hierarchy in LBNE. Future work will extend these studies to more detailed detector configurations and systematic implementation.

10. HARDWARE WORK DONE IN LABORATORY

STRAW FABRICATION

Rectangular plastic sheet of length of dimensions (30cm x 4cm, 40cm x 4cm) for the fabrication of straws tube we used a glass tube to provide a certain

Table 1:

Mass(g)	1 Harmonic(Hz)	II Harmonic	III Harmonic (Hz)
20	124	250	376
30	145	299	450
40	162	326	491
50	188	372	559
60	201	411	614

diameter (8mm to 1 cm). Plastic cap is used as end plug on one side. 20 micron wire is inserted in the straw with the help of needle.

11. MEASUREMENT OF WIRE TENSION

Experiment has been performed in our lab to measure the maximum tension the wire can hold. The principle behind the experiment; when a current is passed through a conductor in a direction perpendicular to that of magnetic field, the conductor experiences a force.

$$F = BIL$$

Where B is magnetic field, I is current, L is length of the conductor. The wire was stretched across the two ends of the sonometer board and masses of the order of grams were hanged. Resonant frequencies were observed for a particular mass and the masses were increased gradually.
The value of the resonant frequency was calculated theoretically using the formula $f = 17.67 / 2rl (\sqrt{} (m/d)$ and the experimentally observed values are closely matching.

12. SUMMARYOF WIRE PROPERTIES

Specific resistance of the gold plated tungsten wire = $0.092\Omega\text{-mm}^2/\text{m}$, Resistance = $\rho l/A$=0.00146 ohms and conductivity = $1.08*10*e^8$ S/m. The wire can hold a tension of maximum 60 grams. This exercise was a preliminary step for developing a technique to read out the wire tension and minimize the gravitational sag of the anode wire.

ACKNOWLEDGEMENT

I would like to thank DST for generous funding. I would also like to thank my supervisor Dr. Vipin Bhatnagar for his guidance and support. I also want to express my gratitude for my colleague Ms. Daisy Kalra for her immense efforts and warm support in laboratory.

REFERENCES

[1] Fermilab Document for wire tension measurement http://lss.fnal.gov/archive/test-tm/1000/fermilab-tm-1125.pdf

[2] GLoBES 3.0 user's and experiment definition manual

[3] P. Huber, M. Lindner and W. Winter, "Simulation of Long Baseline Neutrino oscillation experiment with GLoBES", hep-ph/040733 (2004).

[4] P. Huber, M. Lindner, and W. Winter, "Super beams versus neutrino factories", Nucl. Phys. B 645, 3–48 (2002), hep-ph/0204352. http://dx.doi.org/10.1016/S0550-3213(02)00825-8

[5] Technical Design Report for the PANDA straw tube tracker http://arxiv.org/pdf/1205.5441v2.pdf