PRAMANA
— journal of
physics

Vol. 60, No. 2
February 2003
pp. 405–409

Working group report: Neutrino and astroparticle physics

Coordinators: RAJ GANDHI, KAMALES KAR and S UMA SANKAR

Working Group Members: Abhijit Bandyopadhyay, Rahul Basu, Pijushpani Bhattacharjee, Biswajoy Brahmachari, Debrupa Chakraborti, M Chaudhury, J Chaudhury, Sandhya Choubey, E J Chun, Atri Desmukhya, Anindya Datta, Gautam Dutta, Sukanta Dutta, Raj Gandhi, Anjan Giri, Sourendu Gupta, Srubabati Goswami, Kamales Kar, Namit Mahajan, H S Mani, A Mukherjee, Biswarup Mukhopadhyaya, S N Nayak, M Randhawa, Subhendu Rakshit, Asim K Ray, Amitava Raychaudhuri, D P Roy, Probir Roy, Suryadeep Roy, Shiv Sethi, G Sigl, Arunansu Sil, N Nimai Singh, S Uma Sankar, Mark Vagins and Urjit Yagnik

Abstract. This is the report of neutrino and astroparticle physics working group at WHEPP-7. Discussions and work on CP violation in long baseline neutrino experiments, ultra high energy neutrinos, supernova neutrinos and water Cerenkov detectors are discussed.

Keywords. Neutrino oscillation; CP violation; ultra high energy neutrinos.

PACS No. 14.60.pq

1. Introduction

The working group started with some discussions on some of the areas of interest. A list of these talks is given in table 1. These talks followed by detailed discussions and work on specific problems by smaller groups. P Bhattacharjee, S Uma Sankar and Shiv Sethi suggested problems in the areas of ultra high energy neutrinos, low energy neutrinos and neutrinos in cosmology respectively. We give below a progress report of the work initiated by the working group.

Half a day of the group was spent on talks and discussions on the proposed India-Based Neutrino Observatory (INO) programme.

2. Neutrino oscillation signature at ultra high energies

P Bhattacharjee, R Gandhi and G Sigl

It is proposed to use Glashow resonance

$$\bar{\nu}_e + e^- \Rightarrow W^- \longrightarrow \text{ hadrons} \tag{1}$$

Table 1. List of discussions and speakers in the neutrino and astroparticle physics working group.

CP violation in long baseline experiments	S Uma Sankar
Ultra high energy neutrinos	Pijushpani Bhattacharjee
Neutrinos from supernovae	Kamales Kar
Electroweak interaction rates in hot neutron stars	Günter Sigl
Capabilities of large water Cerenkov detectors for supernovae neutrinos	Mark Vagins
Constraints on 4×4 radiative mass matrix from neutrino oscillation data	Probir Roy
Family symmetry and light sterile neutrinos	Biswajoy Brahmachari
LMA MSW solution from the inverted hierarchical model of neutrino mass	N Nimai Singh
Comparison of signals of supernovae neutrinos in H_2O and D_2O detectors	Gautam Dutta
Indian initiative for a neutrino observatory	Amitava Raychaudhuri
Physics possibilities with the Indian neutrino detector	Anindya Datta
Report on 'Evidence of neutrinoless double beta decay' by the Heidelberg Moscow Collaboration	S Uma Sankar

at $\bar{\nu}_e$ energies of about 6.3×10^{15} eV to detect $\bar{\nu}_e$'s coming from cosmic sources and thereby probe neutrino oscillations at high energies. As the atmospheric neutrino flux falls off fast above a few TeV, there is essentially no background. The possible sources of neutrinos of $E >$ few TeV are from the AGN, the GRB and top-down scenarios of ultra high energy cosmic ray origin. The expected fluxes are known, though somewhat model dependent. Typically the fluxes are $F_{\nu_e}/F_{\bar{\nu}_e} \sim 10$ without oscillation. But one observes that at such energies with maximum mixing $F_{\nu_e}/F_{\bar{\nu}_e} \sim 1$ with oscillation. The idea is to calculate the expected $\bar{\nu}_e$ detection rates in a typical 1 km^3 class detector (ICECUBE, for example) over a small energy range around the Glashow resonance for the expected fluxes with and without oscillation.

Together with the expected ν_e detection rate and knowledge of the spectra of various flavors, one hopes to be able to probe the oscillation parameters. Additional consistency probe of oscillation parameters can be obtained from ν_τ induced 'double bang' event rates, since $F_{\nu_\mu} \simeq F_{\nu_\tau}$ with oscillation.

3. Probing QCD at ultra high energies (UHE) with UHE cosmic rays – evolution of fragmentation functon (FF) from LEP to UHE region

R Basu, P Bhattacharjee, S Gupta and G Sigl

Though one sees UHE cosmic ray (CR) events with $E > 10^{11}$ GeV, these are difficult to explain in the standard scenarios of CR origin. The difficulties are twofold. (i) It is difficult to accelerate particles to $E > 10^{11}$ GeV by shock acceleration mechanisms in astrophysical objects, (ii) the sources of these particles must be within about 50 Mpc from us because of $N + \gamma_{\text{CMBR}} \to \pi + N$ which leads to the Greisen–Zatsepin–Kuzmin (GZK) cut-off. But no suitable sources are yet found within 50 Mpc.

One possible solution is the top-down (TD) scenario where post-GZK events are due to *decay* of some microscopic 'X' particles (from GUT-scale physics, for example) with the mass $m_X > 10^{11}$ GeV. In this scenario, for example X can decay to $X \to q\bar{q} \to \pi' s,\ N' s$ with production of only a few percent N's. The π's decay to photons and neutrinos. Here one makes the hypothesis that the observed UHECR are fragmentation products of the q's. The post-GZK cosmic ray spectrum is determined by the QCD fragmentation function (FF). But the fragmentation function is actually measured at the much lower LEP energies in the $e^+e^- \to$ hadrons. So a large extrapolation to UHE region is required. So the measured UHECR can serve as a probe of evolution of the FF. Some works of quantum chromodynamics (QCD) evolution of FF have already been done by others. The group at WHEPP proposed to do a thorough analysis of various QCD evolution schemes for FF evolution and thereby obtain handles on the uncertainties involved in the extrapolation from LEP to UHE region.

4. Study of possible supernova events in water Cerenkov detectors

G Dutta and K Kar

There are some recent attempts to extract information about the type II supernova (SN) neutrinosphere temperature of $\bar{\nu}_{\mu/\tau}$ with respect to the $\bar{\nu}_e$ temperature from observed events at the water Cerenkov detectors through the highest statistics charged current (cc) reaction $\bar{\nu}_e + p \to n + e^+$ for future galactic SN events at 10 kpc. These utilize the fact that with large mixing angle (LMA) but no resonance, the $\bar{\nu}_e$ spectrum observed should be a superposition of two Fermi–Dirac (FD) distributions (ignoring pinching) with two different temperatures. Through simulations, one uses the possible deviation from a single FD distribution to extract the astrophysical model parameter τ - the temperature ratio $T_{\bar{\nu}_m u/\bar{\nu}_\tau}/T_{\bar{\nu}_e}$.

In the same spirit a study was proposed in the workshop where one considered all possible cc reactions including the ones on ^{16}O (which show order of magnitude increase in the number of events in case of oscillation with respct to the no-oscillation limit) and constructed the total spectrum with τ as a parameter. The purpose was to see at what value of τ one observes the ^{16}O events showing up at the high energy end of the spectrum. One started with typical values of average energies of 16 MeV and 24 MeV for the $\bar{\nu}_e$ and $\bar{\nu}_\mu/\bar{\nu}_\tau$. This gave rise to a total of 271 and 1 events per kton mass of the detector without oscillation for the proton and ^{16}O events respectively. But this study showed that though the ^{16}O events are very sensitive to oscillations, still for typical 3-flavor mixing angles one needs a very high value of τ (~ 2.5) to start seeing the oxygen events dominate over the $\bar{\nu}_e$ events on protons at the high energies.

5. Radiative correction to degenerate neutrino mass

B Brahmachari, E J Chun and Asim K Ray

Let us assume that there exists flavor symmetries which forces the three neutrinos to be degenerate in mass. In practice we need to produce a splitting of order 10^{-5} eV^2 for the solar neutrino oscillation and a splitting of order 10^{-2} eV^2 for atmospheric neutrino transition. It is tempting to think that in such a case the mass degeneracy is lifted by the renormalization group effects. In our analysis we study neutrino mass matrices which give degenerate neutrino mass pattern at some high scale M and calculate the mass splitting generated by renormalization group effects at the scale of neutrino mass. We assume that above the TeV scale there exists minimal supersymmetric standard model. We use SOFTSUSY program to calculate low energy mass spectrum of superparticles.

6. Determining the matter effects and sign of Δ_{31} using a purely a ν_μ beam

A Bandyopadhyay, S Choubey, S Goswami and S Uma Sankar

Wolfenstein term, arising from neutrino propagation in matter, is expected to play a crucial role in the solution to the solar neutrino problem. Observing direct evidence for this matter effect is one of the challenging problems facing neutrino physics. All the proposals to observe this effect (and also obtain the sign of the mass-squared difference Δ_{31}) depend on observing differences in $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$. Recently a proposal was made (Mohan Narayan and S Uma Sankar, *Mod. Phys. Lett.* **A16**, 1881 (2001)) whereby this effect could be observed in an experiment which uses a ν_μ beam alone. It was found that, in $P(\nu_\mu \rightarrow \nu_e)$, the matter effects are dominant in the energy range $0 < E < 2E_{\pi/2}$ and are negligible for $E > 2E_{\pi/2}$, where $E_{\pi/2} = (2.54/\pi)\Delta_{31}L$. Hence even if only ν_μ beam is available, one can isolate the matter effect by comparing the number of electron events in these two energy ranges. This proposal also has some advantages over the neutrino and anti-neutrino beam proposal. Since one needs neutrinos over a large range of energy, a wide band beam is required which is easier to produce. Also the anti-neutrino cross-section is one third the neutrino cross-section. To get data of comparable statistical significance, one needs to take data for three times longer duration with anti-neutrino beam compared to that for neutrino beam. Moreover, the systematics of anti-neutrino beam are likely to be different from those of the neutrino beam. In an experiment which uses purely a neutrino beam, the systematics for the two energy ranges are under better control and statistics will be better because of the higher neutrino cross-section. Here we study the implementation of this proposal for the very high statistics neutrino oscillation experiment *J2K*, which is expected to start in about 2006. Since the detector is water Cerenkov, the electron identification efficiency is very high and this detector can measure $P(\nu_\mu \rightarrow \nu_e)$ very accurately. In this study, we calculate for what values of θ_{13} can this detector isolate the matter effect and determine the sign of Δ_{31}.

7. Effect of large Δ_{21} on the measurement of θ_{13}

A Bandyopadhyay, S Choubey, E J Chun, S Goswami and S Uma Sankar

$\nu_\mu \to \nu_e$ oscillations at long baseline experiments are considered the best option to measure the small mixing angle θ_{13}, which is limited by CHOOZ collaboration to be $\leq 9^\circ$. However, these oscillations can be driven by both the smaller mass-squared difference Δ_{21} and the larger mass-squared difference Δ_{31}. So far, in the sensitivity studies of long baseline experiments for measurement of θ_{13}, Δ_{21} is neglected. But recent solar neutrino results indicate that the solution to solar neutrino problem requires Δ_{21} to be about 10^{-4} eV^2. This large Δ_{21} can lead to $\nu_\mu \to \nu_e$ oscillations at long baseline experiments and limit their sensitivity to θ_{13}. In this study, we calculate how the sensitivity to θ_{13} is limited as a function of Δ_{21} and search for means of improving this sensitivity.

8. CP violation in lepton sector using $\nu_\mu \to \nu_e$ oscillations

Anindya Datta, E J Chun, R Gandhi, H S Mani, A Sil and S Uma Sankar

The best option to look for CP violation in lepton sector is by measuring the difference between $P(\nu_\mu \to \nu_e)$ and $P(\bar{\nu}_\mu \to \bar{\nu}_e)$. However, propagation through matter (which is unavoidable in long baseline experiments) also leads to a difference between neutrino and anti-neutrino oscillation probability and provides a ‘fake’ CP violation signal. The difference caused by CP violation and that caused by matter propagation can be separated by looking at the energy dependence of the signals. In this study, we calculate the energy dependence of these signals and construct appropriate variables which can distinguish between CP violation and matter effects in the most efficient manner.

9. Physics with τ appearance at neutrino factories

Anindya Datta, D Chakraborti, S Dutta, B Mukhopadhyaya and S Uma Sankar

Neutrino factories, based on muon storage rings, can provide well collimated ν_μ and $\bar{\nu}_e$ (or $\bar{\nu}_\mu$ and ν_e) beams of well defined energy. These beams can be used to study a variety of physics topics including matter effects in neutrino propagation and CP violation in lepton sector. In this study, we consider how a measurement of τ appearance in the detector can verify known physics or can constrain new physics.

Acknowledgement

We thank D Majumdar for his help in preparing the manuscript.