Summary of the meeting[1]

1 Introduction

An informal meeting on the "Atmospheric neutrino flux" was held on Feb. 20–21 2001 at the Institute for Cosmic Ray Research, Univ. of Tokyo.

This meeting was the second one dedicated to a critical analysis of the situation of the atmospheric neutrino data and of the possible interpretations.

The data on atmospheric neutrinos is giving what can be considered as robust evidence for the existence of "New Physics" beyond the Standard Model. Oscillations between ν_μ and ν_τ are a viable solution that can provide an accurate description of all existing data.

The calculation of accurate predictions of the atmospheric neutrino fluxes is clearly necessary to obtain as much information as possible about the physical mechanisms that are the source of this "New Physics", and to avoid systematic biases in the determination of the parameters that describe it (for example the oscillation parameters).

2 Experimental Data

The first part of the meeting was dedicated to a discussion of the experimental data, and in particular to the results of the Super–Kamiokande data, that provide the largest existing data set on atmospheric neutrinos. Y. Obayashi, presented a summary of the SK atmospheric neutrino data, and a discussion of the fit to the data in terms of $\nu_\mu \leftrightarrow \nu_\tau$ oscillations. T. Toshito discussed the possible discrimination between the $\nu_\mu \leftrightarrow \nu_\tau$ and the $\nu_\mu \leftrightarrow \nu_{\rm sterile}$ hypothesis. This hypothesis appeared to be disfavored at the 99% C.L.

In addition, a preliminary result on a search for CC ν_τ events was presented. In the absence of oscillations the flux of ν_τ is negligibly small, however in the $\nu_\mu \leftrightarrow \nu_\tau$ hypothesis, one expects an interesting rate of ν_τ CC interactions. The present result was not conclusive, nevertheless, the data were consistent with the existence of of CC ν_τ events in the atmospheric neutrino data with the rate and angular distributions predicted by the $\nu_\mu \leftrightarrow \nu_\tau$ hypothesis.

3 The Primary Cosmic Ray Fluxes

A crucial element in the prediction of the atmospheric neutrino fluxes is clearly a description of the fluxes of primary cosmic rays reaching the atmosphere. The status of our knowledge of the primary cosmic rays has been reviewed by T. Sanuki. The knowledge

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about the primary cosmic ray flux below a maximum rigidity $p/Z \simeq 100$–200 GeV, has improved remarkably thanks to the results of the magnetic spectrometers BESS and AMS.

The data on the p flux of the two experiments are in agreement to a level of better than 5%. It remains to understand the reasons why the recent CAPRICE data has a lower ($\sim 10\%$) normalization, and also a full understanding of the size of the solar modulation effects (new data of BESS will soon be available). For the slightly different p/Helium ratios measured by AMS and BESS could perhaps be due to the corrections applied by BESS to take into account interactions in the residual atmosphere at the balloon floating altitude and inside the detector.

3.1 High energy fluxes

The description of the cosmic ray fluxes above $E_0 \simeq 100$ GeV and up to energies as high as $E_0 \sim 10^5$ GeV is necessary to compute accurately the fluxes of neutrino induced up–going muons. Information on primary cosmic rays in this energy region has been obtained by non–magnetic detectors, as for example the emulsion experiments JACEE and RUNJOB. The data on the atmospheric gamma-ray fluxes (BETS and Emulsion chamber experiments) at high altitude have been suggested as an important measurement strictly related to the primary flux. Tentative fits of the high energy data have been presented by T. Gaisser, M. Honda and P. Lipari. The results are in good agreement among each other. However, in our opinion, the understanding of the high energy cosmic ray fluxes is much poorer than that below 100 GeV. Therefore, a critical discussion is necessary to estimate the systematic errors in the absolute value and spectrum slope of the high energy atmospheric neutrino fluxes (that are most relevant to the upward-going muon measurements). A work along these lines is in progress.

4 Hadronic Interactions

The description of hadronic interactions remains as a significant source of uncertainty in the calculation of the neutrino fluxes. This problem has been the object of contributions of G. Battistoni, T. Gaisser and K. Kasahara that have discussed the models of hadronic interactions in the FLUKA, TARGET and COSMOS Monte Carlo codes. Details of the recent improvements of these models were also reported.

The difference among these models are reflected in differences in the normalization and energy spectrum of the neutrino fluxes that are small (10–15%) but potentially significant.

The significance of the energy fraction (and the Z factor) going into different species of particles has been discussed, in particular the energy fraction into charged pions. The differences that exist among the models can be reflected in effects for the neutrino results. For instance a larger $\langle E_\pi^+ \rangle / \langle E_\pi^- \rangle$ ratio results in a larger $\nu_e/\overline{\nu_e}$ ratio and then in a larger e/μ event ratio. The resulting systematic uncertainty is of order $\sim 2\%$.

An important point would be to analyze critically if the range of differences among these models is smaller or larger than what is allowed by the experimental data, to evaluate a realistic range of uncertainty.

5 Constraints from muon and photon measurements

The measurements of the fluxes of other secondary particles produced in the atmosphere by the hadronic showers of the primary cosmic rays can provide very important constraints on the evaluation of the atmospheric ν fluxes. The muons are most closely related to the neutrinos. T. Sanuki has discussed measurements of the vertical muon fluxes with the BESS spectrometer at ground level for three locations, at Lynn lake in Canada (low geomagnetic cutoff), at Tsukuba (high geomagnetic cutoff), and and Mount Norikura (high altitude at high magnetic cutoff). The data of the CAPRICE detector are in reasonable agreement with the BESS data. These sets of data provide a very important constraint, and the different codes should perform detailed predictions for the muon fluxes in the same conditions of the existing data. Preliminary results show encouraging agreement.

It was commented that atmospheric muon data taken during the ascent of a BESS flight will be available soon.

S. Torii has described measurements of BETS of the photon fluxes and their role as a constraint for the neutrino fluxes. Clearly the relation between the $\pi^{\pm}$ and π° production (and other details of the hadronic interactions) have to be correctly described for precision results. It was noted that two data sets of gamma rays, taken at the balloon altitude and at the mountain altitude, are very useful to constrain the detailed properties of the hadronic interaction models.

6 Calculation schemes

The calculation of the atmospheric neutrino fluxes is a non–trivial technical task. Going beyond the One–Dimensional approximation (where the neutrinos are collinear with the primary particle) is computationally demanding. Different methods to take into account more realistically of the emission angle of the neutrinos (including also the effects of bending of the shower particles in the geomagnetic field) have been discussed. The different algorithms give results that are in good agreement between each other, with an enhancement for the horizontal directions. The average transverse momentum of the final state pions is important to estimate the size of the enhancement (with a larger $p_{\perp}$ corresponding to a larger enhancement). The role of the bending of muons in the geomagnetic field also requires a careful study.

7 Calculation of the neutrino fluxes

At the workshop three different groups have compared independent calculations of the atmospheric neutrino fluxes. The three groups are a "Japanese group" (M. Honda, T. Kajita, K. Kasahara, S. Midorikawa), the "Bartol" group (G.Barr, R. Engel, T. Gaisser, P. Lipari and T. Stanev) and the "Fluka" group (G. Battistoni, A. Ferrari, T. Montaruli, P.R. Sala, T. Rancati). All three groups have published calculations of the atmospheric neutrino fluxes and are actively working on more refined calculations, that should be completed with a time scale of a few months. The meeting was an occasion for the three groups to cross–check their results and prepare for a discussion of the systematic uncertainties.

It is reassuring that the results of the three groups are reasonably close to each other, is such a way that the interpretation of the data does not change dramatically using the three different predictions. Moreover the differences among the three calculations, at least to a good approximation can be understood as the consequence of differences in some elements of the calculations (primary flux, hadronic interaction models, and inclusion (or not) of 3D effects, giving confidence that the systematic uncertainties are reasonably well understood and under control.