Proceedings of ICRC 2001: 966 © Copernicus Gesellschaft 2001

ICRC 2001

Atmospheric gamma-ray observations with BETS for calibrating atmospheric neutrino flux calculations

K. Kasahara[1], E. Mochizuki[1], S. Torii[2], T. Tamura[2], K. Yoshida[2], T. Ouchi[2], J. Nishimura[3], T. Yamagami[3], Y. Saito[3], H. Murakami[4], T. Kobayashi[5], Y. Komori[6], T. Yuda[7], M. Honda[8], and S. Midorikawa[8]

[1]Shibaura Institute of Technology, 307 Fukasaku, Omiya 330-8570, Japan
[2]Kanagawa University, 3-27-1 Rokkakubashi, Kanagawa-ku, Yokohama 221-8686, Japan
[3]Institute of Astronautical Science, 3-1-1 Yoshinodai, Sagamihara 229-8510, Japan
[4]Department of Physics, Rikkyou University, 3-34-1 Nishiikebukuro, Toshima-ku, Tokyo 171-8501, Japan
[5]Aoyama Gakuin University, 6-16-1 Chitosedai, Setagaya-ku, Tokyo 157-0071, Japan
[6]Kanagawa Prefectural College, 1-5-1 Nakao, Asahi-ku, Yokohama 241-0815, Japan
[7]Solar-Terrestrial Environment Laboratory, Nagoya University, Furoucho, Chigusa-ku, Nagoya 464-8601, Japan
[8]Institute of Cosmic-Ray Research, 5-1-5 Kashinoha, Kashiwa 277-8582, Japan
[9]Aomori University, 2-3-1 Yukihata, Aomori 030-0943, Japan

Abstract. To calibrate simulation calculations for the neutrino flux, we have carried out observations of atmospheric gamma-rays in the GeV region at balloon altitudes and at Mt.Norikura (2770m a.s.l). The balloon flights were successfully done in 1999 and 2000 at an altitude from 15 km to 25 km. The results show that the interaction code (Fritiof1.6) used in the HKKM calculation (Honda et.at, 1995) gives slower development of cosmic ray showers than the observation. The Lund Fritiof V7.02 was found to give fairly consistent results with the observed energy spectra and the altitude variation of gamma-ray flux.

1 Introduction

The super-Kamiokande group has found evidence of neutrino oscillation (Fukuda et al, 1998) through the analysis of atmospheric neutrinos. Comparisons of the data with expected fluxes obtained by Monte Carlo calculations show deficit of muon type neutrinos; its zenith angle dependence strongly suggests $\nu_\mu \rightarrow \nu_\tau$ oscillation and hence finite neutrino mass. The conclusion is derived in such a way that it is not upset by the uncertainty of the absolute flux values in the current calculations. However, to be able to discuss the problem in more detail we should have reliable absolute flux estimation.

The uncertainty of the atmospheric neutrino flux comes mainly from the uncertainty in 1) the primary cosmic ray flux and 2) propagation of cosmic rays in the atmosphere (mainly the modeling of nuclear interactions), and estimated to be order of $\sim$ 30 %.

The recent proton primary fluxes measured by the BESS (Sanuki , 2000) and AMS (AMS group, 2000) groups coincide very well up to $\sim$ 100 GeV, and seem very reliable. The helium component has been also measured by the both group with rather good agreement. Therefore, the first problem has almost been resolved at least for low energy neutrinos. This fact helps examine nuclear interaction models by comparing calculated fluxes with observations for various atmospheric cosmic-ray components. We have carried out atmospheric gamma-ray observations at a mountain altitude (Mt.Norikura, 2770 m a.s.l) and at several balloon altitudes from 15 km to 25 km for such a purpose.

In this article, we mainly report the results obtained by a balloon flight in 2000.

Correspondence to: K. Kasahara
kasahara@icrr.u-tokyo.ac.jp

2 Detector

We have been using the BETS detector of which the details before being upgraded for gamma-ray observation is given in (S.Torii et al , 2000). The detector uses $\sim$ 10 K scintillating fibers of 1 mm diameter sandwiched between lead plates. This makes possible to get fine imaging of cascade shower and offers important means for differentiating pure electromagnetic showers from hadronic ones. The total thickness of the lead plates is 7.1 radiation lengths. For the event trigger, three plastic scintillator plate, each being 1 cm thick, are set at the top (S1), middle (S2) and the bottom (S3). The top area of the detector is 28 cm $\times$ 28 cm.

S1 is separated by 15 cm from the main body of the detector. As anti-counters we have another wider top scintillator plate covering the whole detector cross-section, and 4 side anti-counters as seen in Fig.1. The performance of the detector has been tested and established by accelerator beams (electrons, protons and pions) at CERN(Tamura et al , 2000).

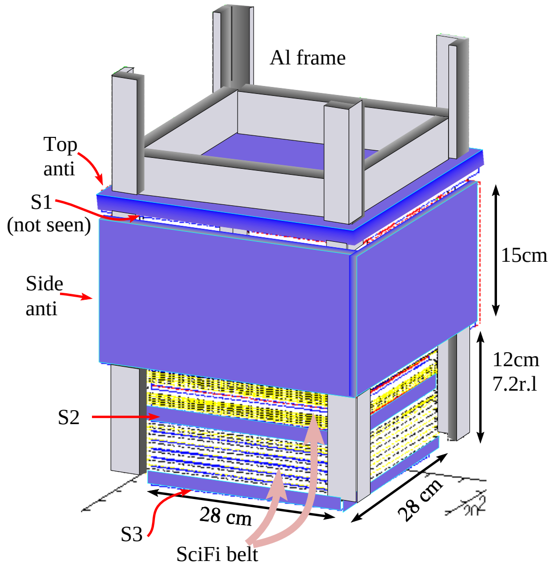

Fig. 1. Schematic view of BETS detector

3 Balloon Flight in year 2000

We had a successful balloon flight in Jun. 5, 2000 from the Sanriku balloon center of the ISAS; the balloon of 42,475 m^3 was launched at 6:50 and recovered at 17:59 on the sea. Figure2 shows the balloon being launched and flight curve showing nearly complete level flight at 4 different altitudes.

The number of triggered events, the observed gamma rays etc are summarized in Table 1

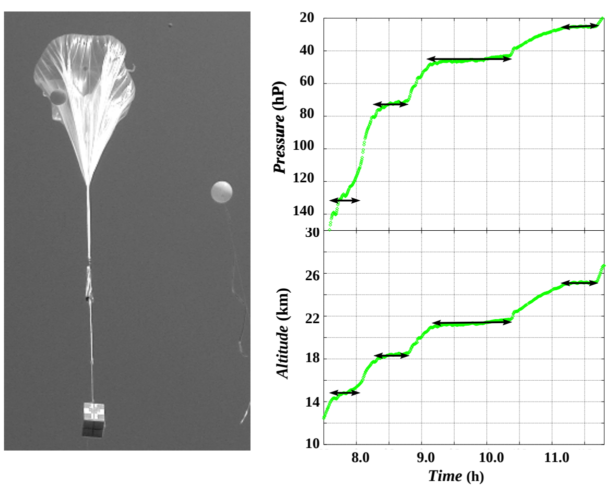

Fig. 2. The balloon payload picture just after the launching, and the flight curves

Level flight	I	II	III	IV
<Height>(km)	15.3	18.3	21.4	25.1
<Depth>(g/cm^2)	128	73	45.7	25.3
Duration (sec)	1,560	2,160	4,320	2,320
Live Time (%)	48.2	43.0	42.6	44.2
Trig.d Events	18,808	25,795	46,675	17,436
# of γ candidates	1,306	1,485	2,299	740

Table 1. Characteristic parameters in 2000 balloon observation

4 Gamma-Ray Flux

4.1 Event selection

The trigger condition of the events is summarized in Table 2. In the table, we show the discrimination levels (in unit of MIP number) of signals in each scintillator. The γ-low mode is mainly responsible for relatively low energy gamma rays for which back splash effect is not serious. As energy goes higher, the back splash effect becomes sizable and the gamma-low mode efficiency decreases so we prepared the γ-high mode. The cross-over of the modes takes place at around 30 GeV. In the current analysis, we used only the gamma-low mode. Among the triggered events, the following criteria were adopted to select the events for the data analysis: 1) The shower axis crosses S1 and S3. At S3, the crossing position is inside 20 mm from the edge. 2) The zenith angle of the shower axis is less than 30 degrees. From these selections, the only source of background against gamma rays is neutron induced showers. This is estimated by a Monte Carlo simulation and if we take the showers with energy concentration > 0.7, contamination is estimated to be completely negligible ($< 1\%$).

Mode	S1	S2	S3
Gamma-High	< 3.0	> 1.59	> 3.18
Gamma-Low	< 0.47	> 5.0	> 8.1

Table 2. Trigger mode for gamma-ray observation

Figure 3 shows the observed distribution of energy concentration which is defined as the energy deposit portion within 5 mm from the estimated shower axis. For comparison, we show also the same distributions which were observed by the CERN electron beams. It is seen that the experimental distribution is consistent with these by the electron beams. It has almost no hadronic showers which distribute mainly in the region < 0.7.

4.2 Energy Determination

The energy calibration has been done by the CERN electron beams in 1997. However, for 2000 observation we have changed the electronic circuit and the calibration could not be used directly. So we employed a Monte Carlo simulation partly; first we made a simulation corresponding to the CERN experiment to verify the validity of the simulation.

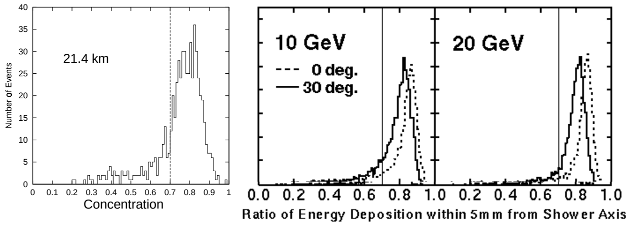

Fig. 3. Distribution of the energy-concentration ratio in the observed events at 21.4 km (left) and in the electron beams (right).

The result was quite satisfactory within 0.5 % differences. To get the absolute scale of the energy value, we used cosmic ray muons. The energy is estimated by (S2+S3) value at low energy (< 20 GeV) and S3 value at higher energies. The typical r.m.s energy resolution in % is 25 (3 GeV), 19 (10 GeV), 15 (30$\sim$ 50 GeV) and 20 (100 GeV). Its slight zenith angle dependence (2$\sim$3 %) is taken into account in the analysis.

4.3 Flux correction

The gamma-ray flux at each observation depth was calculated by using the live times and the the geometrical factors ($S\Omega$) estimated by simulations (Torii, 2000). The final energy spectrum was obtained by imposing the following correction factors that were not included in $S\Omega$. They come from:

1. Accuracy of shower axis fitting. Our fitting method has a small systematic bias, and this leads to $\sim$4% overestimation of the flux at balloon altitudes.

2. Multiple particle incidence. A gamma ray may accompany charged particle(s) generated by one and the same primary. The simulation tells that, in almost 100 % cases, they plunge into the detector within 1 ns and vetoes the gamma-low trigger. There are cases that they are multiple gamma-rays (this is less than the charged particle case); they would be judged as hadronic showers by the energy concentration criterion. These lead to underestimation of the flux; the correction factor is larger for higher energies and deeper depths. At altitudes $>$ 20 km and energy below 10 GeV, it is less than 1 %. The percentage correction factor (energy in GeV) list at 15 km is: 2(3), 4(10) and 9(30).

3. Finite energy resolution. The steep energy spectrum and energy dependent resolution leads to spillover effect among histogram bins. This leads to the overestimation of the flux. A typical percentage correction factor (energy in GeV) list is: 10(3), 5(10) and 2(30).

4.4 Energy Spectrum and Interaction models

In Fig.4 the observed gamma-ray energy spectra at different altitudes are presented and compared with simulated results.

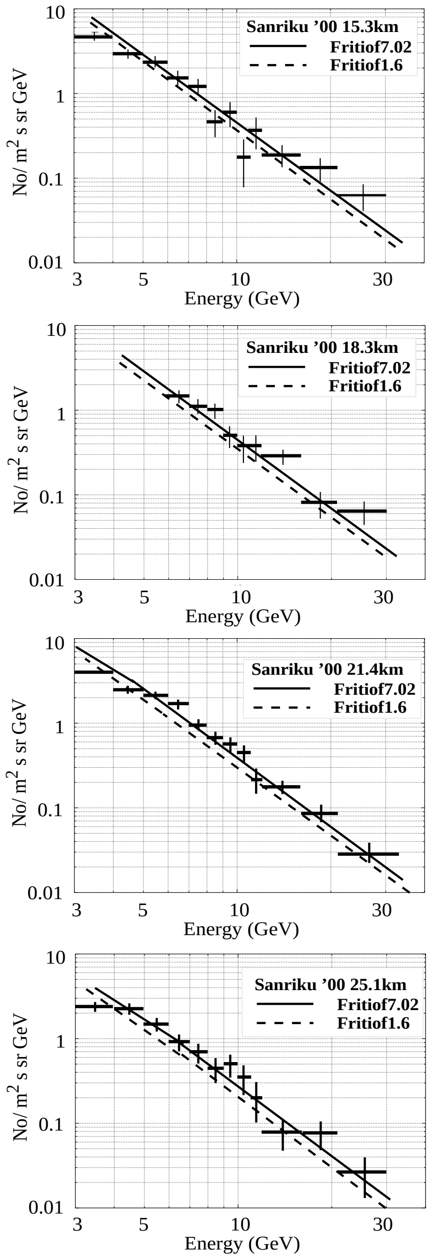

Fig. 4. Observed gamma-ray spectra at balloon altitudes are compared with Monte-Carlo calculations

In the simulation we assumed the BESS proton and helium primaries. In addition to these we also considered primary electrons (by AMS) and CNO component. As nuclear interaction models we employed two different codes; one is Lund Fritiof1.6 (Almqvist, 2000) and the other is Fritiof7.02 (Pi, 1992). The former is the one used in the HKKM calculation (Honda et.at, 1995). Showers by v7.02 show faster development and attenuation than those by v1.6. This feature is consistent with the observation and also seen in Fig.5 which shows the transition of gamma-ray flux above 6 GeV from

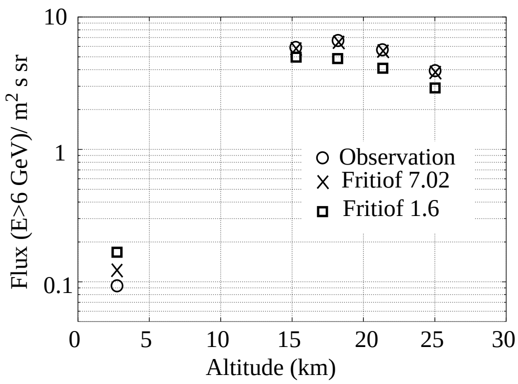

Fig. 5. Altitude variation of gamma-ray flux over 6 GeV. Faster development and attenuation is consistent with Fritiof7.02

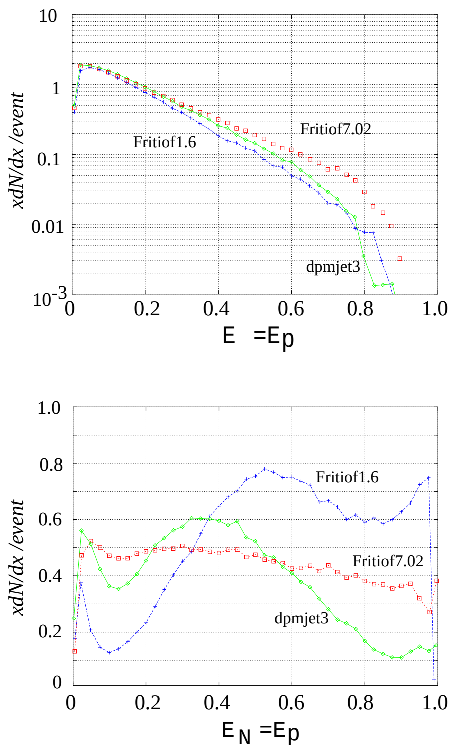

Fig. 6. The x-distribution in proton nitrogen collisions at 30 GeV. x is defined as the kinetic energy ratio. Upper: pion distribution. lower: nucleon distribution. Fritiof 7.02 and dpmjet3 have a harder pion spectrum and higher inelasticity than v1.6

the balloon to the mountain altitudes.

The difference by two interaction models comes from the difference between the x-distributions as shown in Fig.6

5 Conclusions

We have found that Monte-Carlo calculations using the Lund Fritiof V7.02 as a nuclear interaction model and the BESS flux as a primary proton and helium can give fairly consistent results with the gamma-ray observations at balloon altitudes and at 2770 m. We are now testing another model (dpmjet3; (Roesler, 2000)) which not only shows even better agreement with the gamma ray data than Fritiof7.02 dose but can give also a good description of muon data.

With these good models, it is expected that the neutrino flux at sea level will have the following features as compared with the HKKM calculation. At low energies, the flux should be lower than the HKKM value while at higher energies, the relation is reversed. The crossover takes place at few GeV.

Acknowledgements. We sincerely thank the team of the Sanriku Balloon Center of the Institute of Astronautical Science for their excellent service and the support of the balloon flight. This work is partially supported by Grants-in Aid for Scientific Research B (09440110) and Grants-in Aid for Scientific Research on Priority Area A (12047224).

References

Honda, M. Kajita, T. Kasahara, K. and Midorikawa, S. *Phys. Rev.* D **D52**, 4985 (1995).
Sanuki, T. et al.,*ApJ* **545**, 1135 (2000)
AMS collaboration, *Phys. Lett.* B **490**, 27 (2000).
Fukuda, Y., et al., *Phys. Rev. Lett.* **81**, 1 (()1998)
Torii, S. et al., *Nucl. Instrum. Methods* A **452**, 81 (2000)
Tamura, T. et al., *Adv. Space Res.* **26**, 1397 (2000).
Torii, S. in *Neutrino Oscillations and their Origin*,ed. Y Suzuki, M.Nakahata, M.Shiozawa, K.Kaneyuki (Universal Academy Press, INC., Tokyo, 2000)
Almqvist, B.N. Stenlund, E.; Comp.Phys.Comm. **43**, 387 (1987)
Pi, H. Comp. Phys. Comm. **71**, 173A (1992)
Roesler,S. Engel, R. and Ranft J., SLAC-PUB-8740, hep-ph/0012252, to be published in Proceedings of the the Conference "Monte Carlo 2000", Lisbon, Portugal, 23-26 October 2000