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Neutrinos and Dark Matter

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There has been incredible progress in the last few years in the understanding of the neutrino, and the 2005 International Cosmic Ray Conference in Mumbai included many presentations about solar, atmospheric, reactor and accelerator neutrino experiments. At the same time, a growing community of cosmic ray physicists are preparing to study high energy neutrino astronomy with large neutrino telescopes which are being built. Searches which are still negative continue for other phenomena, such as magnetic monopoles and Weakly Interacting Massive Particles. This rapporteur report will survey these developments.

1. Introduction

The subjects of neutrinos and related topics continues to be a popular one at the International Cosmic Ray Conference. Tremendous progress has been made up to and since the discovery of neutrino oscillations and neutrino mass in 1998[1] particularly using cosmic ray neutrinos. The knowledge about neutrinos continues to grow using atmospheric and solar neutrinos, though the increase in knowledge is now concentrating on quantitative and not qualitative features of understanding the mixing parameters. It is expected that further understanding in the nature of the neutrino will come in the related fields of accelerator neutrinos, using off-axis beams, and reactor neutrinos using multiple detectors underground.

The last few years have seen a large growth in physicists paying attention to the field of High Energy Neutrino Astronomy. Initial results have been reported by Baikal and AMANDA, which ambitious projects in various stages of construction include ANTARES, NEMO, NESTOR, Ice-cube, and AUGER. Ambitious ideas for neutrino detection using acoustic and radio waves continue to receive serious attention.

The topics that I will review in rapporteur report are solar neutrinos, atmospheric neutrinos, results in High Energy Neutrino Astronomy, plans in High Energy Neutrino Astronomy, Dark Matter, and a few other topics that are lumped together as exotica. The subjects of muons and supernova neutrinos, which in the past were quite popular at ICRC, were covered in a dwindling number of papers this year. The topics gravity and neutrinoless double beta decay were the subject of no papers, as was the case for proton decay, a topic in which our host country, India, once led the world. Ironically, some interesting results were not presented at this conference, such as solar neutrino results from SNO[2], or the recent discovery of geoneutrinos by KamLAND[3]. This makes it difficult for this review to be comprehensive on any subject. Also, given the large number of topics to summarize, inadequate attention will be given to three topics that were covered by Highlight talks and will also appear in this proceedings, Cosmic Ray Studies at L3[4], Ice-Cube[5] and the combined theoretical and experimental context for neutrino physics[6].

2. Atmospheric Neutrinos

The atmospheric neutrino problem had been around for many years, before the conclusive demonstration of neutrino oscillations by Super-Kamiokande in 1998[7]. That detector had a major accident in December 2001. They quickly rebuilt with lower phototube coverage, and the new results of "Super-Kamiokande II" have been presented at this conference, along with updated analyses of "Super-Kamiokande I". There were two interesting new results from Super-K on atmospheric neutrinos. They reported that using data from a

627 day exposure of Super-Kamiokande II, all effects that had been reported in the 1489 day exposure of Super-Kamiokande-I were reproduced[8]. Consistent rates and angular distributions were obtained for the fully contained, partially contained, and upward going muon event samples, for both the muon-type and electron-type events. The allowed regions for neutrino oscillation parameters, usually referred to as Δm^2_{31} and $\sin^2(2\theta_{23})$ are shown in Figure 1 and are seen to be consistent up to the difference in statistics. The best fit for SK-I is located at $\sin^2(2\theta_{23}) = 1.00$ and $\Delta m^2_{31} = 2.5 \times 10^{-3} eV^2$. At 90% confidence level (CL), the allowed parameters are $\sin^2(2\theta_{23}) > 0.93$ and $2.0 \times 10^{-3} < \Delta m^2_{31} < 3.2 \times 10^{-3} eV^2$. For SK-II, the best fit is $\sin^2(2\theta_{23}) = 0.98$ and $\Delta m^2_{31} = 3.1 \times 10^{-3} eV^2$. The corresponding 90% CL parameters are $\sin^2(2\theta_{23}) > 0.85$ and $1.2 \times 10^{-3} < \Delta m^2_{31} < 5.5 \times 10^{-3} eV^2$.

In a new analysis focusing on those events with the best L/E resolution, Super-K also reported evidence for the expected dip in the L/E distribution [12]. This is shown in Figure 2. A search for tau appearance in SK-I found a best fit tau signal of 145 ± 48(stat) $^{+0.4}_{-36.2}$(syst) and are consistent the with the expected rate of tau neutrino appearance[13].

New data was also shown by Soudan 2, which added the upgoing stopping muons to their global fit[9]. The no-oscillation hypothesis can now be rejected with Soudan 2 data alone with a chance probability of 3.2 $\times 10^{-5}$. MINOS presented its first atmospheric neutrino data, both with contained events[10] and upward going muons[11]. From the first 408 days exposure, 107 contained events were reported. With the oscillation hypothesis, the expected number of up/down, track/shower and positive/negative ratios were seen. The non-oscillation hypothesis was excluded at 98% CL. There were 91 upward going neutrino induced muons observed in 464 days. The data and expectations are consistent within the current statistical errors. An investigation of the effect of seasonal variations on the neutrino flux, relevant for neutrino telescopes was presented in Reference [14]. The calculations show a variation ranging between 0.5% and 3% depending on the geographical latitude, which is too small to be resolved within the limited statistics of high energy atmospheric neutrinos from the AMANDA-II detector. However, km^3 detectors will have the statistics to see these effects.

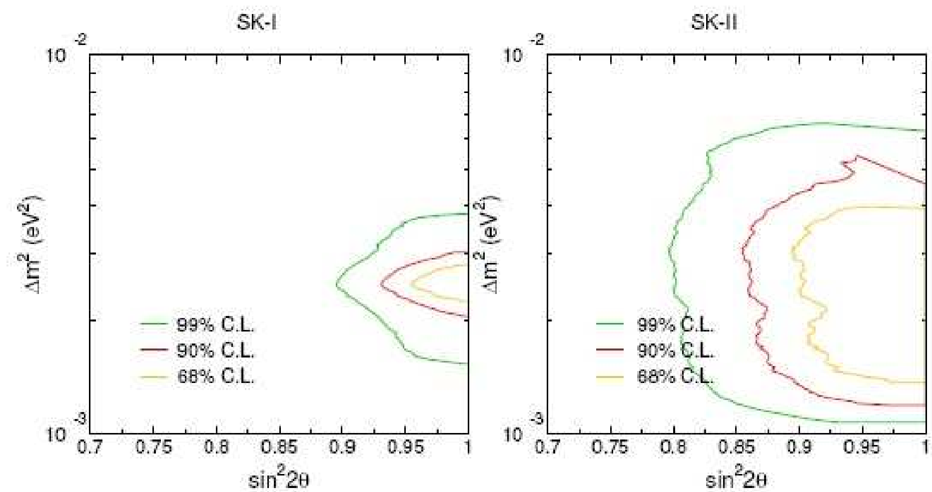

Figure 1. Parameter space for atmospheric neutrino oscillations measured separately by Super-Kamiokande I and Super-Kamiokande II[8]

There continue to be improvements in the atmospheric neutrino models. Using the HKKM04 code and atmo-

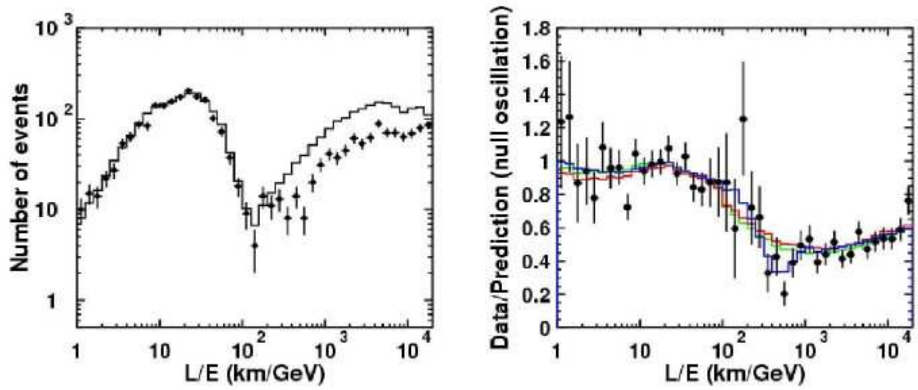

Figure 2. On the left is the no-oscillation expected L/E distribution from Super-Kamiokande I (histogram) along with the measured data[12]. On the right the ratio of the two is shown and the dip characteristic of neutrino oscillations can be seen at L/E = 500 km/GeV. The best fit oscillation expectation is shown, along with two models that do not have a dip.

spheric muon data, improvements can be made to the DPMJET-III interaction model to improve agreement with data[15]. Another group is working to use the Super-Kamiokande spectrum itself to constrain the extrapolation of the neutrino spectrum to high energy[16]. The Super-K data and also air-shower data suggest a relatively hard spectrum. An important contributing factor is that Kaons become the dominant source of neutrinos above 100 GeV, as seen in Figure 3.

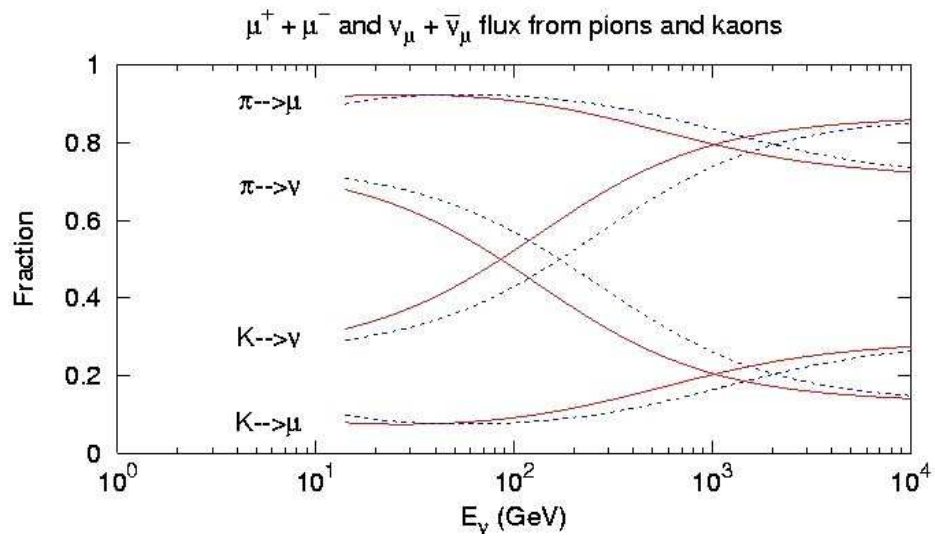

Figure 3. The relative contributions to muons and neutrinos as a function of energy from pions and Kaons[16]. The solid line is for the vertical direction and the dotted line is for 60^o.

3. Solar Neutrinos

The long standing solar neutrino problem has been solved. Solar neutrinos start in a flavor eigenstate ν_e when they leave the sun, but propagate as a mixture of mostly ν_1 and ν_2, arriving at the earth as a mixture of all three flavors.

One of several contributors to the solution of this puzzle has been Super-Kamiokande. A summary of solar neutrino results from Super-Kamiokande I and new results from Super-Kamiokande II were shown in Reference [17]. The angular distributions of both data sets are shown in Figure 4. Since there were less phototubes in Super-Kamiokande II, the low energy cut had to be raised from 5 MeV to 7 MeV to beat down single photons coming from the glass of the phototubes. Despite the lower phototube coverage, it is seen that the angular resolution of the two data sets are similar. The measured ^{8}B solar neutrino fluxes were 2.35 $\pm$ 0.02(stat) $\pm$ 0.08(syst) $\times$ 10^6/cm^{2}s in SK-I and 2.36 $\pm$ 0.06(stat)$^{+0.16}_{-0.15}$(syst) $\times 10^6$/cm^{2}s(preliminary) in SK-II. A search for a spectral distortion and a day-night asymmetry resulted in no significant deviation from flat/symmetry respectively. When combined with data from the SNO salt phase[18] and KamLAND[19], parameters measured are Δm^2_{21} = 79 meV^2 and $\sin^2\theta_{12}$ = 0.31.

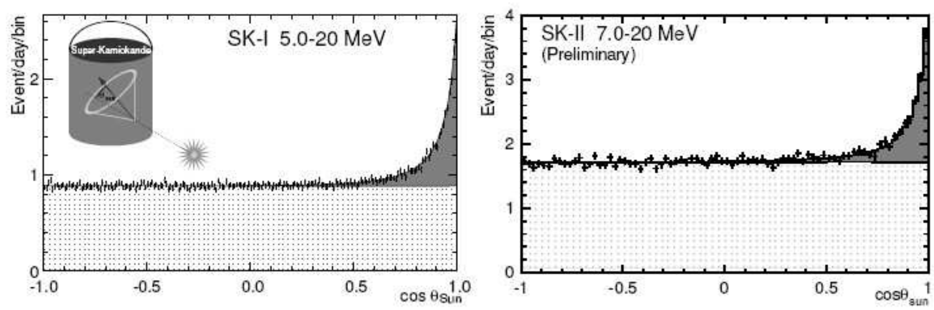

Figure 4. Angular Distribution of Solar Neutrino Event Candidates in SK-I (Left) and SK-II (Right)[17].

It seems a shame to summarize the solar and atmospheric neutrino results with just four numbers: $\sin^2(2\theta_{12})$, $\sin^2(2\theta_{23})$, Δm^2_{31} and Δm^2_{21}. I consider this good news (while some might think it is bad news) that the world's neutrino data is all consistent with this framework. Extensive reviews exist in the literature about the interesting ways that we got to this situation[20]. The fifth mixing angle, thc might be accessible with future solar, atmospheric or supernova experiments, but only with large and unlikely increases in sensitivity and/or unusual mixtures of parameters. The interesting open questions in neutrino physics, such as what is θ_{13}, and is θ_{23} maximal or not, along with the mass hierarchy, mass scale and Dirac/Majorana nature of the neutrino seem to have their answers in fields outside of the cosmic ray purview. But who knows?

4. Results from High Energy Neutrino Astronomy

Current experiments in the field of High Energy Neutrino Astronomy include AMANDA-II at the south pole and NT200 at Lake Baikal. AMANDA-II has been upgraded with transient waveform recorders[21]. At Lake Baikal, the NT200 array has been supplemented by three outrigger strings 1100 m away (see Figure 5)[22]. This is called NT200+. Projects under development which are beginning to see cosmic rays include ANTARES in the Mediterranean, NESTOR in the Mediterranean, NEMO in the Mediterranean, and ICE-CUBE at the South Pole.

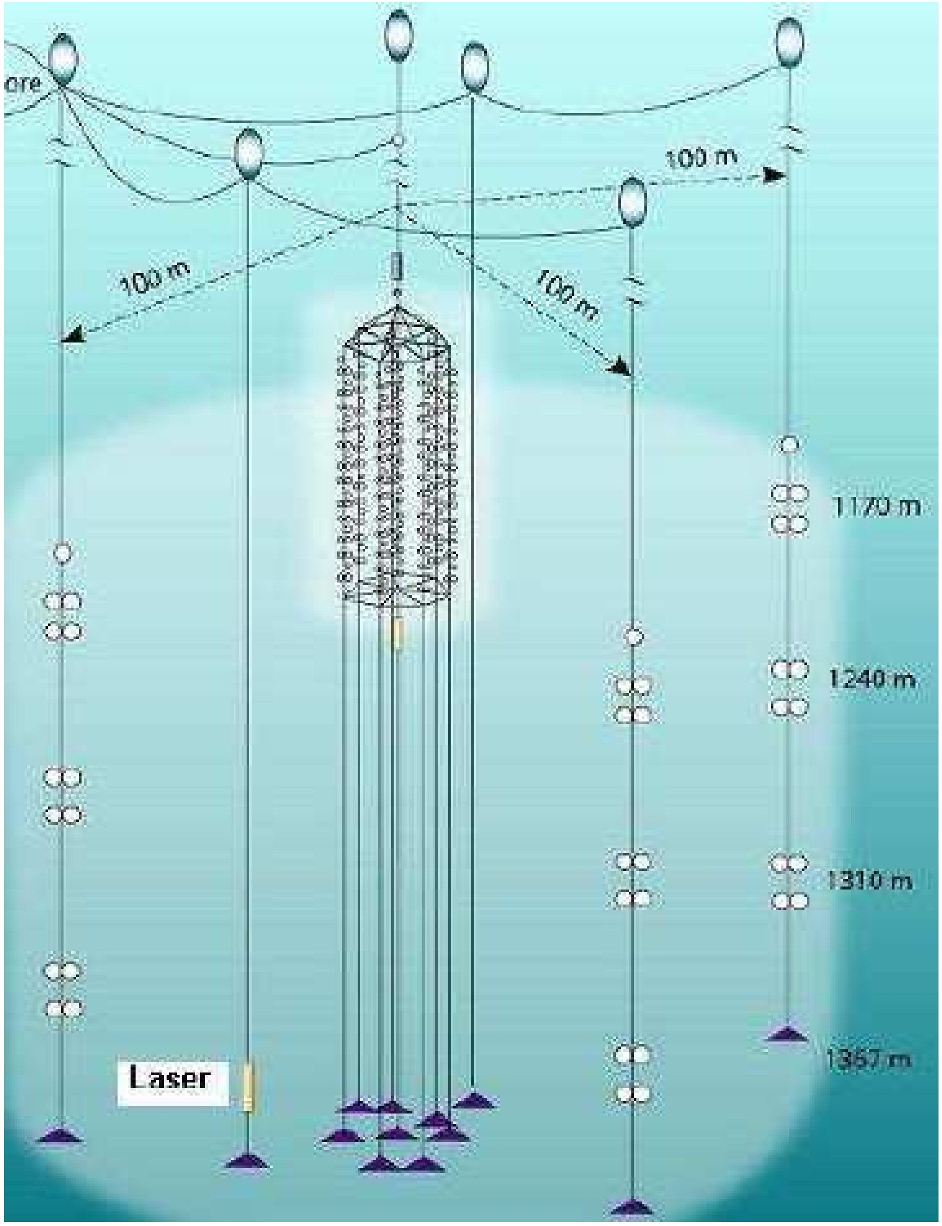

Figure 5. The Baikal NT200+ Detector.

The search can be described as just beginning, but so far there are no compelling observations of neutrino sources. The results from AMANDA and NT200 are consistent with backgrounds from atmospheric neutrinos. These neutrino telescopes are finally beginning to assemble statistics comparable to upward going fluxes from detectors built to search for proton decay. For example, Super-Kamiokande reported an analysis of 1892 upward going neutrino induced muons[23]. AMANDA reported on analyses of 3329 neutrino candidates taken from 2000-2003[24, 25]. They looked for a steady source of neutrino emission from selected objects in the sky[25]. This table is shown in table 1. It is interesting that the largest excess is found in the direction of the Crab Nebula, the first TeV gamma ray source. Given the number of objects observed, the observation of 10 events with a background of 5.4 is not unexpected. But with additional observation time, perhaps this will grow into a signal by the time of the next cosmic ray conference. AMANDA-II also reported a search for neutrino emission in coincidence with TeV Blazars and Microquasars, observed in γ-ray wavelengths, and also for neutrino flares[24] whose times and durations are unknown. No statistically significant excess of events over the background expected was observed. Although the results obtained were not significant, the time structure of the neutrino candidates from the direction of the blazar 1ES 1959+650 were intriguing. Three events out of the five fall within 66 days (MJD 52394.0, 52429.0, 52460.3). The period of time in which these three events fall is partially overlapping with a period of exceptional high activity of the source. An AMANDA-II search for events in coincidence with 73 Gamma Ray Bursts yielded a limit assuming a Waxman-Bahcall like spectrum[26] $A_{90}^{allflavors} < 9.5 \times 10^{-7} cm^{-2} s^{-1} sr^{-1}$GeV[27]. Another search for 500 GRBs yielded no coincidences[28]. A search for neutrinos from the galactic plane yielded a limit $< 4.8 \times 10^{-4} cm^{-2} s^{-1} sr^{-1}$GeV^{-1} for a spectrum E$^{-2.7}$[29].

Table 1. Results from AMANDA-II search for neutrinos from selected objects[25]. δ is the declination in degrees, α the right ascension in hours, n_{obs} is the number of observed events and n_b the expected background. Φ_ν^{lim}, is the 90% CL upper limits in units of =$10^{-8} cm^{-2} s^{-1}$ for a spectral index of 2 and integrated above 10 GeV. These results are preliminary (the systematic errors are under assessment).

Candidate	$\delta(^\circ)$	α(h)	$n_{\rm obs}$	n_b	$\Phi_\nu^{\rm lim}$	Candidate	$\delta(^\circ)$	α(h)	$n_{\rm obs}$	n_b	$\Phi_\nu^{\rm lim}$
TeV Blazars											
Markarian 421	38.2	11.07	6	5.6	0.68	1ES 2344+514	51.7	23.78	3	4.9	0.38
Markarian 501	39.8	16.90	5	5.0	0.61	1ES 1959+650	65.1	20.00	5	3.7	1.0
1ES 1426+428	42.7	14.48	4	4.3	0.54						
GeV Blazars											
QSO 0528+134	13.4	5.52	4	5.0	0.39	QSO 0219+428	42.9	2.38	4	4.3	0.54
QSO 0235+164	16.6	2.62	6	5.0	0.70	QSO 0954+556	55.0	9.87	2	5.2	0.22
QSO 1611+343	34.4	16.24	5	5.2	0.56	QSO 0716+714	71.3	7.36	1	3.3	0.30
QSO 1633+382	38.2	16.59	4	5.6	0.37						
Microquasars											
SS433	5.0	19.20	2	4.5	0.21	Cygnus X3	41.0	20.54	6	5.0	0.77
GRS 1915+105	10.9	19.25	6	4.8	0.71	XTE J1118+480	48.0	11.30	2	5.4	0.20
GRO J0422+32	32.9	4.36	5	5.1	0.59	CI Cam	56.0	4.33	5	5.1	0.66
Cygnus X1	35.2	19.97	4	5.2	0.40	LS I +61 303	61.2	2.68	3	3.7	0.60
SNR & Pulsars											
SGR 1900+14	9.3	19.12	3	4.3	0.35	Crab Nebula	22.0	5.58	10	5.4	1.3
Geminga	17.9	6.57	3	5.2	0.29	Cassiopeia A	58.8	23.39	4	4.6	0.57
Miscellaneous											
3EG J0450+1105	11.4	4.82	6	4.7	0.72	J2032+4131	41.5	20.54	6	5.3	0.74
M 87	12.4	12.51	4	4.9	0.39	NGC 1275	41.5	3.33	4	5.3	0.41
UHE CR Doublet	20.4	1.28	3	5.1	0.30	UHE CR Triplet	56.9	11.32	6	4.7	0.95
AO 0535+26	26.3	5.65	5	5.0	0.57	PSR J0205+6449	64.8	2.09	1	3.7	0.24
PSR 1951+32	32.9	19.88	2	5.1	0.21						

Limits on the diffuse flux of AGN neutrinos were presented by Baikal's NT200[30] and by AMANDA-II[31]. A plot showing the limits is given in Figure 6. For an E^{-2} behavior of the neutrino spectrum, the Baikal limit is $E^2\Phi_\nu(E) < 8.1 \times 10^{-7} cm^{-2} s^{-1} sr^{-1}$GeV over an energy range $2 \times 10^4 - 5 \times 10^7$ GeV[30]. The limit from AMANDA for data during the year 2000 is $E^2\Phi_\nu(E) < 2.6 \times 10^{-7} cm^{-2} s^{-1} sr^{-1}$GeV[31]. A number of features in Figure 6 are worth noting. Experiments actually observe the presence or absence of muons of unknown energy. To turn this into a flux of neutrinos requires a model of both the neutrino cross section and the energy spectrum. The limits shown in the figure all assume an energy spectrum E^{-2} over the entire energy regime, which might not be a realistic model. It is conventional to extend the lines over the energy range where 90% of muons would be observed if there was a signal; i.e. 5% of muons which barely trigger would be lower energy than the left edge of the line, and 5% of muons with high energy and lower flux would be beyond the right edge of the line. Also, full mixing of neutrinos arriving at the detector in the ratios $\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$ is assumed, as would be expected for neutrinos arising from pion decay together with maximal θ_{23}. Above 10^6 GeV, the attenuation of neutrinos in the earth must be taken into account, and the signal would be concentrated near the horizon where there is background from muons in cosmic ray showers. AMANDA presented a limit from data during 2000 for an E^{-2} spectrum of $E^2\Phi_\nu(E) < 3.8 \times 10^{-7} cm^{-2} s^{-1} sr^{-1}$GeV for an energy range between 1.8 $\times 10^5$ GeV and 1.8 $\times$ 10^9 GeV[32].

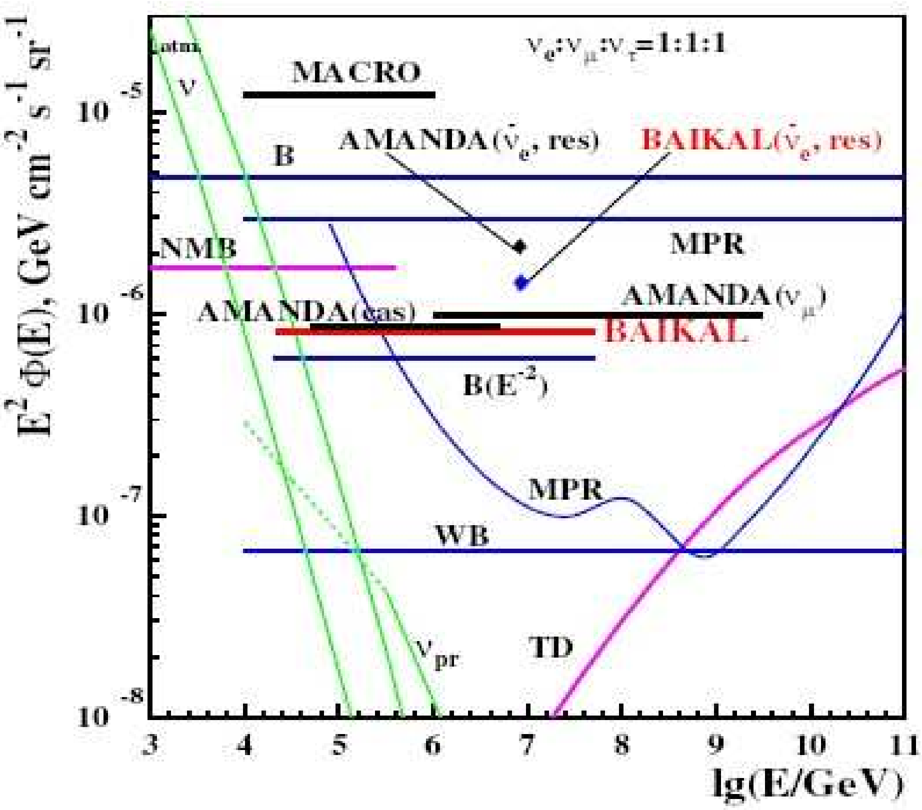

Figure 6. Limits on the diffuse flux of neutrinos from AGNs, from [30].

As the number of neutrino telescopes and hence the exposure time for Neutrino Astronomy grows, it is increasingly important to understand the tests that will be used to define whether or not there is an excess in some direction for some set of conditions. In searches for cosmic ray sources, it is recognized to be important to specify those tests A-priori. A large number of potential source type exist[33]. A look at the properties of the sources for steep spectra was presented in Reference [34]. The implications of stacking sources of a similar type was studied in Reference[35]. ANTARES has developed an unbinned likelihood ratio search method which is superior to binning techniques[36].

5. Plans for High Energy Neutrino Astronomy

While the results from AMANDA and Baikal are interesting, it is undoubtedly true that the best is yet to come.

The ANTARES Collaboration is building an undersea neutrino telescope off the French coast at a depth of 2500 m. This will consist of 900 photomultipliers (PMTs) arranged in 12 strings. The arrival times of Cerenkov photons on the PMTs will be registered with an accuracy of about 1 ns, which will result in an angular resolution of a few tenths of a degree for the reconstruction of a high energy muon track. Two test lines were deployed in the spring of 2005[37]. An evaluation of the background due to atmospheric muons in ANTARES was calculated in Reference[38].

NESTOR is 4000 meters deep and located 7.5 nautical miles from the island of Sapienza, 30 km from a shore station in Methoni Greece, where the land end of an electro-optical cable is terminated. The basic element of the NESTOR detector is a hexagonal floor or star, with two phototubes at the end of each arm. So far a test module has been used to measure the zenith angle distribution of muons[39].

ICE-cube is being built at the south pole near the AMANDA site, as described in [5]. Phototubes for IceCube are being tested and calibrated at Chiba University before installation[40].

NEMO is a project to identify a suitable km^3 site off the coast of Sicily[41]. A prototyping activity has been launched in order to implement a reduced-scale demonstration, which is called NEMO Phase 1. The site is at 2000 m depth at a distance about 25 km from the coasts of Sicily, and is equipped with an electro-optical cable connected to a shore station inside the Port of Catania. The goal is to complete this stage by the end of 2006. Optical noise rates for an 8" PMT with a threshold of 0.3 pe have been measured at 28 kHz at a depth of 3000 m[42]. They also measured the absorption and attenuation lengths in the blue region of 66m and 35m respectively.

While the ideas are not new, techniques for observing large neutrino showers using acoustic and radio observations have received substantial new attention. A hybrid optical/radio/acoustic extension to IceCube for EeV neutrino detection was described[43]. A key component is the development of cheap but sensitive acoustic sensors[44]. ANTARES is equipping each of its 12 strings with 6 hydrophones[45] which are under development[46] and plans to achieve 3 cm accuracy on their positioning. A background noise spectrum was measured during the spring of 2005[47]. A much more ambitious scheme[48] envisions deploying 200 acoustic modules per square kilometer over $30 \times 50 \times 1$ km^3 which are sensitive to bipolar acoustic signals above 5 mPa, to reconstruct neutrinos with energies above 1 EeV and sensitive below the extrapolated Waxman-Bahcall flux and GZK neutrino flux[49].

Radio detection could focus on an underground salt dome which provides better transparency to radio wave propagation than ice[52]. The RICE experiment, which consists of 16-20 radio antennas deployed within a roughly 200m $\times$ 200m footprint at depths of 100m-300m near the South Pole, reported no neutrinos with data taken between 2000 and 2004[50]. That data can be used to bound models of low scale gravity[51]. The most promising radio experiment appears to be ANITA[53]. ANITA is a balloon-borne radio-pulse detector system designed to measure Ultra-High Energy (UHE) neutrinos interacting in the Antarctic ice utilizing the distinct broadband radio pulse due to the Askaryan effect. A sketch of the apparatus is shown in Figure 7. ANITA will have an effective viewing area of over one million km^2 of ice at float altitude (37 km). A prototype experiment, ANITA-LITE, was flown during the 2003-2004 Austral Summer from Antarctica to perform an impulsive RF background survey of Antarctica. In the process, it has already yielded strong constraints on UHE neutrinos. The first full ANITA flight is planned for a 2006 Austral Summer launch out of McMurdo, Antarctica.

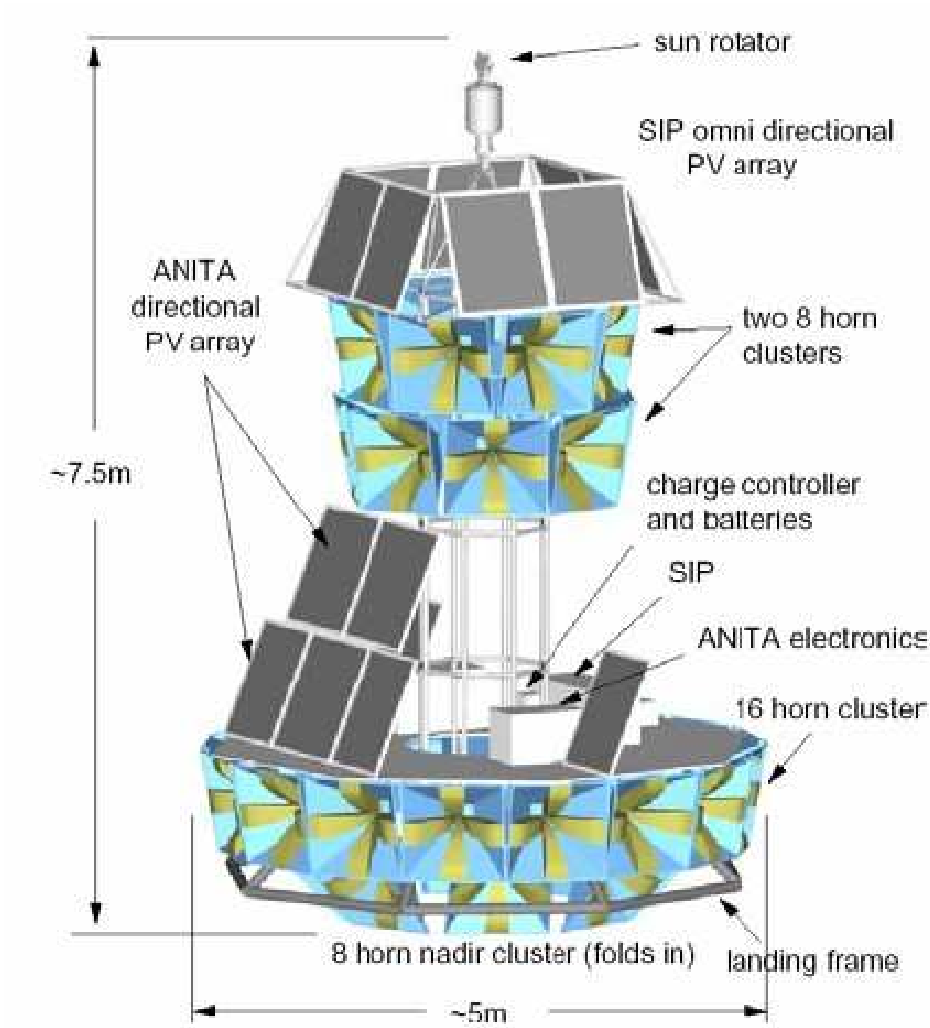

Figure 7. Sketch of the ANITA instrument with major components labeled[54].

Another technique for detecting high energy cosmic ray showers is for an air shower array to focus on most horizontal showers, that have gone through so much atmosphere that a hadronic primary is unlikely to have survived. The largest air shower array is now AUGER[55]. The expected rates for AUGER for neutrinos from Active Galactic Nuclei and Topological Defects vary from 0.2 to 5 events for a variety of models,[56], though the expected rates from Gamma Ray Bursts are negligible, i.e. $< 2 \times 10^{-4}$ events. Earth skimming Tau-Neutrinos provide an especially interesting signal for which to search[57]. It is also possible for an Air Cerenkov Telescope at high altitude to look down[58].

6. Dark Matter

Dark Matter is known to exist from both cosmological arguments and from the rotation curves of galaxies. There are a variety of searches for the direct evidence of dark matter, some of which were covered at this conference and some of which were not. Searches for direct evidence of dark matter are taking place at many places underground, as well as accelerators. Many experiments are looking for weakly interacting massive particles (WIMPs) which would interact elastically with nuclei, generating a recoil energy of a few tens of keV, at a rate smaller than 1 event $kg^{-1}d^{-1}$. To reduce backgrounds, detectors sensitive to these signals are underground. A signal for an annual modulation due to WIMPs has been reported by the DAMA Collaboration[59], but it is refuted by Edelweiss and CDMS[60, 61].

Results presented at this conference are based on gamma rays and neutrinos which might originate from the locations of dark matter annihilation, particularly of the SUSY variety, sometimes called neutralinos. This might take place in the earth, in the sun, or throughout the galaxy. An excess of diffuse gamma rays from the

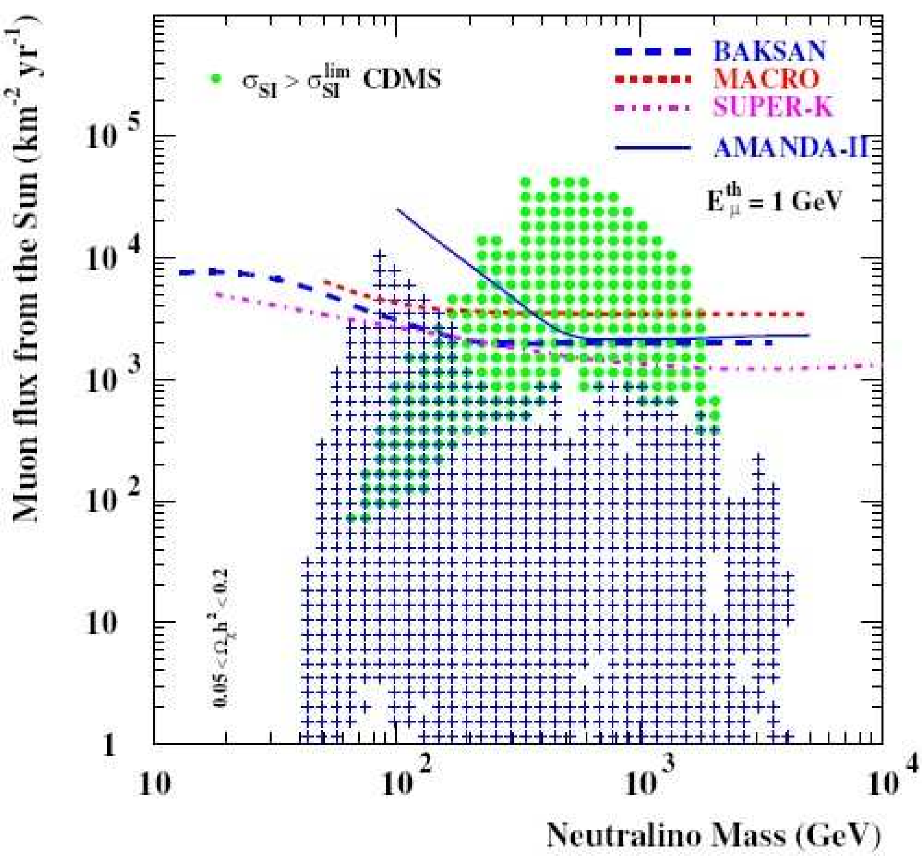

Figure 8. 90% CL upper limit on the muon flux coming from hard neutralino annihilations in the center of the Sun compared for several experiments[63]. Markers show predictions for cosmologically relevant MSSM models, the dots represent parameter space excluded by CDMS[60]

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Egret data is reported in Reference [62]. The interpretation of this excess requires a complete understanding of the energy spectrum of several backgrounds, along with the energy resolution of the Egret detector. AMS02 will be able to confirm or deny this signal[64]. A search for excess events in AMANDA from the direction of the earth and the sun yielded no significant excess[63]. A collection of indirect searches for neutralinos from the sun is shown in Figure 8.

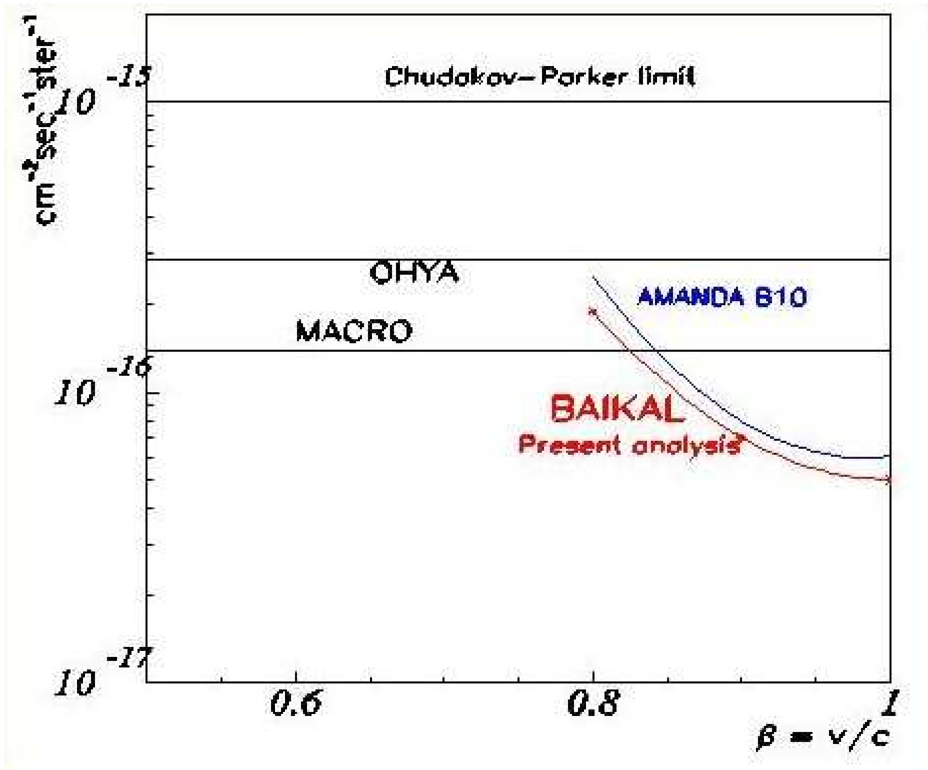

Figure 9. 90% CL upper limits on the flux of fast monopoles from Baikal, OHYA, Amanda-B and MACRO[66].

7. Exotica

Cosmic Ray experiments have historically had the opportunity to search for a large variety of unexpected things. The phenomenon of neutrino oscillations may have recently fit into this category, but no longer. The subject of neutrino oscillations got a strong boost when experiments that were designed to search for proton decay carefully measured their backgrounds. The search for proton decay itself, may be considered unfinished business. Proton decay is still an unverified prediction of almost all Grand Unified Theories. The progress in reducing the limits on nucleon decay, and the plans for new experiments, have long been reported at Cosmic Ray Conferences. Interestingly, there were no contributions in this field at this conference. There are plans for bold new experiments to study nucleon decay, such as UNO and Hyper-Kamiokande[65]. These plans will undoubtedly take time and be reported upon at future International Cosmic Ray Conferences.

Lake Baikal's NT200+ detector took advantage of its outriggers and reported a new search for relativistic magnetic monopoles[66], and obtained a flux limit as shown in Figure 9. The SLIM experiment at Chacaltaya (5290 m a.s.l.) also looked for monopoles using CR39 in the mass range 10^5 to 10^9 GeV[67]. From the analysis of 171 m^2 for 3.5 y, they set a flux limit for monopoles, nuclearites and Q-balls of any speed coming from above of at the level of 3.9 $\times 10^{-15} cm^{-2} sr^{-1} s^{-1}$. The L3+C detector made a negative search for Kolar events, unstable particles with a large invariant mass[68]. The corresponding event flux upper limit at 90% c.l. is $7.1 \times 10^{-13} cm^{-2} s^{-1} sr^{-1}$.

8. Conclusion

Neutrino oscillations are firmly established, but attention now turns to some of the key unanswered questions that are left. What is the value of θ_{13}? MINOS may be able to push the limits a small amount[69]. It is likely that the next level of improvement on θ_{13}, and perhaps a discovery, could come from reactor experiments. The best current limit comes from the CHOOZ reactor experiment[70]. Six new projects are currently under consideration around the world[71]: ANGRA in Brazil, Braidwood in the USA, Daya Bay in China, Double Chooz in France, KASKA in Japan and RENO in Korea. The one likely to happen first is Double Chooz[72]. If a nonzero value of θ_{13} can be established, then CP violation in the lepton sector could be explored at superbeam experiments planned at JPARC in Japan and Fermilab in the U.S. At the same time, the possible Majorana nature of the neutrino can be probed in neutrinoless double beta decay experiments, while the overall mass scale of the neutrino sector is being probed in KATRIN. Supernova neutrinos are another interesting topic that received scant attention at this conference. It is possible that Super-Kamiokande is on the verge of discovering supernova relic neutrinos[17].

One new proposed neutrino experiment deserves special mention. There is a plan for an ambitious new atmospheric neutrino detector, the Indian Neutrino Observatory or INO. This was described in a highlight talk at this conference[73]. It is ironic that the most remarkable progress in neutrino physics came from studying atmospheric neutrinos, but no large experiment dedicated to atmospheric neutrinos has ever been funded. Perhaps if INO is funded, it will show the wisdom of such an investment.

In the next few years, the number of sensitivity of neutrino telescopes searching for high energy neutrinos will greatly increase. We may be on the verge of some exciting discoveries. However, this large community of physicists has to be prepared for the possibility that no high energy neutrinos will be detected. The gamma ray community continues to debate whether the highest energy gamma rays are of electromagnetic origin, which would imply no accompanying neutrinos, or of hadronic origin, which would imply neutrinos at some level. Perhaps the large number of sources reported by HESS[74] gives some hope that at least some of these sources are of hadronic origin. Whatever the case, future sessions on neutrinos and exotica at future International Cosmic Ray Conferences are bound to have new and interesting results.

9. Acknowledgments

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