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NEUTRINO ASTRONOMY AND WEAKLY INTERACTING PARTICLES

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1 Search of exotic particles

The search of new exotic particles as a component of the cosmic radiation is one of the main field of investigation of cosmic rays physics since a long time.
More recently the large detectors placed in underground laboratories permit a very sensitive search of penetrating particles.
It has to be remarked that in several theoretical models some particles are expected to be so massive that their production in accelerators is impossible. The cosmic rays experiments are therefore the only tool for a possible identification of objects like monopoles, nuclearite, etc.
Moreover several of these particles are *dark matter* candidates with a series of consequent constraints among abundances, masses, interactions.

1.1 Monopole

The search of a very massive ($\sim 10^{16} GeV$) magnetic monopole is going on since t'Hooft [1] and Polyakov [2] showed that this particle is a necessary consequence of the symmetry breaking which produces the electromagnetic group $U(1)$.

Due to its very large mass the monopole is expected to be very penetrating despite its very high ionization loss. A monopole ionizes about ten times more than a minimum ionizing particle at $\beta \sim 10^{-3}$ with a strong increase with velocity.
Therefore the search is performed looking for highly penetrating, highly ionizating, low β particles. Two new results have been presented in this conference

- H E 6.1.1 (Kolar Gold Field) and
- H E 6.1.2 (SOUDAN 2)

the limits on the Monopole flux are respectively:

$$\begin{array}{lll} \Phi < 1.810^{-15} cm^{-2} sr^{-1} s^{-1} & & \beta \geq 1.4\ 10^{-3} \\ \Phi < 2.410^{-14} cm^{-2} sr^{-1} s^{-1} & & 10^{-3} \leq \beta < .95 \end{array}$$

In Fig. 1 an (uncomplete) compilation on monopole flux limits is given.
Concerning future searches H E 6.1.4 presents an experiment making use of thermoluminescent ($BaSO_4Eu$) technique.
In this detector slow massive particles would be detected by the light (fluorescence and thermoluminescence) emitted.
A very important remark with respect to monopole searches making use of $CR-39$ technique has been presented in H E 6.1.3.
Studying the response of $CR-39$ to low velocity ($\beta \leq 10^{-2}$) ions the authors find that it behaves differently from the restricted energy loss model. This result extrapolated to the $CR-39$ response to a monopole excludes that a low velocity ($\beta \leq 10^{-1}$) monopole could be detected with this technique [Fig.2].

1.2 Nuclearites

The possible existence of a stable phase of quark matter *nuclearites* has created much interest in the last few years.
E. Witten [3] proposed the possibility that matter consisting of roughly equal number of *up*, *down*, and *strange* quarks may be stable in a wide range of mass values. If strange matter is stable it must be an abundant component of the cosmic radiation.
A search for nuclearites has been reported in HE 6.3.1 (MACRO). The experiment placed in Gran Sasso underground laboratory (~3000 m.w.e.) was looking at slow and large light production in a scintillation system.
The results are summarized in Fig. [3].
Concerning future experiments it has been presented in HE 6.3.4 a ballon program consisting in a hybrid instrument in which the masses of the candidates are determined by measuring the Cerenkov and scintillation light yield.
Another method making use of radio signals at extremely low frequency induced by the passage of nuclearites at deep sea has been presented in HE 6.3.7.

1.3 Weakly Interacting Massive Particles

Supersymmetric theory investigated as a possible extension of the standard model, produces new phenomena at the $10TeV$ scale or below.
A set of new particles *partners* of the known ones should be produced in the future supercolliders (LHC, SSC). A very attractive features of the supersymmetry is that it provides a natural dark matter candidate: the *neutralino.* The supersymmetric partners of the photon, neutral weak boson and two Higgs form four-neutral states, the lightest of those is the stable *neutralino* χ.
The unsuccesful LEP search has placed limits on the neutralino mass ($\leq 45GeV$) [4]. The search of neutralino - a massive weak interacting particle - as a component of cosmic radiation follows two different approach.

a) Direct search

The detection of the recoil energy of the nuclei in an interaction of the kind

$$\chi + A \rightarrow \chi + A$$

This approach has been discussed in HE 6.2.1 and HE 6.3.5.
The first contribution reports on the program carried on at the underground laboratory of Boubly to develop low background, large mass solid state detectors capable to put significant limits on the neutralino search.
In the second contribution the idea to use Mica to identified target recoil is discussed.

b) Indirect search

A high energy ($E_v \geq 10GeV$) neutrino flux coming from the Sun is an indirect signature of the neutralino as dark matter candidate. The Sun will capture neutralinos by coherent scattering of nuclei.
The neutralinos trapped in the sun annihilate into neutrinos.
In HE 6.2.3 this effect is extensively discussed and it is shown that a neutrino telescope of $\sim .1$ KM^2 area will be an excellent instrument to search for neutralinos up to mass of $1TeV$.

2 Muon-Astronomy

In 1985 the SOUDAN 1 [5] and NUSEX [6] experiments reported underground muons from the direction of Cygnus $X-3$.
These muon signals may indicate that high energy photons with a high energy interaction producing muons with unexpected high probability (HE 4.1.1) or a new type of stable neutral particle is emitted by Cygnus $X-3$ [Fig.4].
Since then Cygnus $X-3$ as well as other possible sources have been monitored by several experiments looking at muons coming from their directions.

In this conference several contributions have been reported in this kind of searches. HE 4.3.2 and HE 4.3.4 reported results obtained in surface experiments making use of magnetic spectrometers to select energetic muons. The first experiment has seen an excess of muons from Cygnus (with rather poor statistical evidence) corresponding to a flux $\Phi \simeq 3.2 \pm 1.1\, 10^{-10} cm^{-2} s^{-1}$; the second obtains a null result corresponding to $\Phi \leq 2 10^{-9} cm^{-2} s^{-1}$.
The result from the underground experiments has been reported in HE 4.3.6 (MACRO) and HE 4.3.8 (SOUDAN 2) with no significant effect found as steady or modulated signal.
The situation is summarized in Tab. 1,2,3 and in Fig.[5].

Table 1
Search of steady muon signals from point sources (MACRO)

Source	depth (mwe)	n	n_{bkd}	A_{eff} (m^2)	f	F_{steady} $(cm^{-2}s^{-1}$
CygX3	3960	491	485	190	.66	$< 7.4 \times 10^{-13}$
HerX1	3885	455	489	194	.64	$< 7.5 \times 10^{-13}$
1E2259+59	3795	584	608	183	1.0	$< 5.7 \times 10^{-13}$
crab	3560	520	523	200	.52	$< 9.3 \times 10^{-13}$

Table 2
Search for a modulated muon signal from point sources (MACRO)

Source	P_0	$W(> nR^2$	$W(> \Upsilon_n$	$F_{mod}(cm^{-2}s^{-1}$
CygX3	4.8^h	0.90	0.52	$< 6.9 \times 10^{-13}$
HerX1	1.70^h	0.52	0.68	$< 4.1 \times 10^{-13}$
HerX1	34.9^d	0.64	0.32	$< 6.8 \times 10^{-13}$

Table 3
Search of steady muon signals from point sources (SOUDAN 2)

Source	*Observed*	*Expected*	*Excess %*	*Stat.Error %*
1E2259+586	4776	4812.5	-0.8	1.4
Crab	3069	3120.0	-1.7	1.8
Hercules X-1	3533	3551.8	-0.5	1.7

An interesting puzzling effect has been presented as a possible sporadic emission from Cygnus $X - 3$ in coincidence with the January '91 Radio burst. On January 19th the 8GHz radio flux from Cygnus $X - 3$ rose rapidly to peak at $15 Jy$ on the 21st. It then decayed to $3.5 Jy$ on the 25th.

In this *period* - in the lack of a specific model correlating radio emission with high energy photon the time useful to define a coincidence is somewhat arbitrary - a series of positive and negative observations of muons from Cygnus has been reported.

We summarize the results in the following table.

Table 4. Muons from Cygnus X-3. January 91

Exp.	depth (mwe)	day	Signal events	Backgr. events	muon-flux $cm^{-2}s^{-1}$
IMB	1500	20			$< 6\,10^{-10}$
		23			$< 4\,10^{-10}$
SOUDAN 2	2000	20	16	5.3	$\sim 8\,10^{-10}$
		23	16	6.1	$\sim 7\,10^{-10}$
MACRO	3700	17-24			$\leq 4.5\,10^{-11}$
K.G.F.	6000	17	2	0.1	
		19	2	0.1	

It is very difficult to give any conclusion by the reported results. Future observations will help to clarify the existence of this effect.

Finally it is worth mention various theoretical and experimental contributions concerning $\mu-$physics not correlated with $\mu-$astronomy. In particular HE 4.1.2, 4.1.3 present a detailed theoretical treatment of the propagation of the muons in the rock.

An experimental study of $\mu-$interactions in the NUSEX iron calorimeter has been reported in HE 4.1.7. A measure of the muon charge ratio in the energy interval $0.2 \leq E_n(GeV) \leq 200$ is presented in HE 4.1.5 and a study of the arrival time distribution of underground muons have been reported by MACRO in HE 4.2.7.

3 Neutrino-Astronomy

The observation of neutrinos produced in various sources (Sun, Supernova, atmosphere) has open an entirely new field in the study of cosmic radiation. The weak interaction of neutrinos with matter makes its detection very difficult but the carried informations extremely useful. While in fact the photons are easily shielded, the neutrinos can cross large amount of material with small attenuation. Therefore the ν-astronomy is often a powerful tool to investigate the core of stellar objects.

The main topics of neutrino astronomy in increasing order of ν-energy are:

- Solar neutrino. This subject will be covered by Prof. G. Kocharov in a separate talk.
- neutrinos from gravitational collapse
- Atmospheric neutrinos
- VHE, UHE neutrino astronomy

3.1 Stellar Collapse

Since the detection of a neutrino burst from SN 1987 A [7] a large amount of work has been dedicated to the optimization of the performances of several experimental set up.
The detection of $\bar{\nu}_e$ burst from collapsing stars ($< E_{\bar{\nu}_e} > \approx 10 MeV, \bar{\nu}_e$ burst duration $\sim 10s$) is mainly based on $\bar{\nu}_e$ interactions of the kind $\bar{\nu}_e + p \rightarrow n + e^+$ followed by delayed neutron capture in hydrogen $n + p \rightarrow \gamma + d$ with $E_\gamma \simeq 2.2 MeV$.
The scintillation counters may also detect the process

$$\nu_{e,\mu,\tau} + C \rightarrow \nu_{e,\mu,\tau} + C + \gamma \qquad\qquad E_\gamma \simeq 15 MeV$$

of special interest because sensitive to neutrinos of any flavour.
In this conference large scintillator detectors LSD (HE 5.1.6), MACRO (HE 5 .3.17) and LVD (HE 5.3.3) have presented a status report of the experiments . In summary in a near future (Feb. '92) a total of ~ 800 Tons of liquid scintillators will be in operation together with the large water Cerenkov detectors (IMB, Kamiokande). This mass is capable to detect hundreds of $\nu-$ interactions from a S.N. explosion occurring in our galaxy.

3.2 Atmospheric neutrinos

Cosmic ray air shower produce both ν_e and ν_μ with typical energies of 1 GeV from pions, kaons and ν's decay.

$$\begin{aligned} p + A_{ir} \rightarrow \quad & \pi^+ \quad + \pi^- + \ldots \\ \rightarrow \quad & \mu^+ + \nu_\mu \\ & \rightarrow e^+ + \nu_e + \bar{\nu}_\mu \end{aligned}$$

A prediction of the ν_μ's and of ν_e's fluxes has been presented in HE 5.2.5. Some of these atmospheric neutrinos will interact in large underground detectors. Two of these detectors have reported a discrepancy between the predicted and the observed ratio of $\frac{\nu_\mu}{\nu_e}$ charged current events with a deficit of ν_μ induced events [8][9]. The ν_e and ν_μ fluxes are measured by identifying electrons and muons in the interactions occurring inside the detectors.

$$\begin{aligned} \nu_e \quad + \quad & N \rightarrow e + \ldots \\ \nu_\mu \quad + \quad & N \rightarrow \mu + \ldots \end{aligned}$$

The experimental situation is summarized in Tab. 5

Table 5.
$\left(\frac{\nu_e+\bar{\nu}_e}{\nu_\mu+\bar{\nu}_\mu}\right)$ from four experiments

	Measured	Expected	nr. events
FREJUS 1.56kT-yr	0.85±0.16 (stat)	0.74	122 (contained)
NUSEX 0.74 kT-yr	0.56±0.16(stat)	0.56	50
KAM-II 3.43 kT-yr	1.05±0.14(stat)	0.64	178 (after cuts)
IMB-3 3.4 kT-yr HE 5.1.1	1.43±0.19(stat)	0.99	236 (after cuts)

From that table one can see that the ν_μ deficit is present in the two experiments (IMB, Kamiokande) that use water as target while the experiments (FREJUS, NUSEX) consisting in segmented iron calorimeters show a good agreement between predicted and observed $\frac{\nu_e}{\nu_\mu}$ ratio.
A possible explanation of the ν_μ-deficit may be the nuclear corrections of the neutrino interactions in the two different materials.
Further investigations are needed on this subject. Future additional measurements are proposed by SOUDAN 2 presenting in HE 5.1.5 its capability in muon/electron separation for atmospheric neutrino interactions.
Atmospheric neutrinos are also a powerful tool to study neutrino oscillations. The oscillation probability at a distance L(km) is given by the expression

$$P(\nu_\mu \rightarrow \nu_e) = \sin^2(2\alpha)\sin^2\left(1.27\Delta m^2\left(\frac{L}{E}\right)\right)$$

α is the mixing angle
$\Delta m^2 = m_1^2 - m_2^2$ (m_1, m_2 neutrino masses in eV)

E is the neutrino energy in GeV.
The detected neutrinos are produced at a distance of the order of the earth diameter; the long path corresponds to good sensitivity for very small Δm^2 values.
A new limit on ν-oscillation parameters has been reported in HE 5.1.2 (IMB). The results presented in Fig. [6] are obtained by measuring the up going $\mu-$flux and the ratio between the stopping and non-stopping muons produced in $\nu-$interactions in the rock below the detector.

3.3 V.H.E., U.H.E. neutrino astronomy

The search for sporadic or steady sources of high energy ($\geq 10GeV$) extraterrestrial neutrinos is a fascinating field of astronomy growing up very fastly.

The energetic neutrinos expected to be created by π decay produced in hadronic interactions are the best tool to understand acceleration mechanisms occurring inside astrophysical objects.
Moreover since gamma rays can be easily absorbed in the source or on the way from the source to the detector, neutrinos enable a totally new way to look at the sky with the potential to reveal new unexpected phenomena.
From an experimental point of view the high energy neutrino telescopes are performed with μ-detectors capable to identify upgoing muons produced in $\nu-$interactions in the surrounding rock [Fig. 7]

$$\nu_\mu + N \to \mu + X$$

The neutrino direction is practically the same as that of the reconstructed muon; the angle between the two being in average very small.
At U.H.E. ($E_v \geq 10^6 GeV$) the neutrino cross section becomes large enough that the $\nu-$flux is strongly attenuated in the earth. Therefore the detection in this energy region must be done looking at nearly horizontal showers induced by $\nu-$interactions.
Up to now neutrino telescopes have been developed in underground laboratories to be shielded against the cosmic rays muon background. This choice implies an obvious limitation in the detector surface of $\sim 1000 m^2$.
The neutrino telescopes of the future generation, one or two order of magnitude larger than the present ones, must be built out of underground laboratories.
In this conference the results of a search of point sources has been presented, the flux expected from possible sources of V.H.E. and U.H.E. neutrinos have been theoretically investigated and several projects of future telescopes have been reported. The present limits given by IMB on high energy neutrino point sources, together with the results of other experiments is given in Tab. 6.

Table 6
Point source flux and luminosity limits (IMB)

Source	$F_\nu$limit $10^{-6} cm^{-2} s^{-1}$ $E_\nu > 2GeV$	This work	Luminosity Kamiokande	limits IMB-1	in erg/s FREJUS
Cen X-3	4.24	$2.82 \cdot 10^{38}-$ $-1.13 \cdot 10^{39}$			
Cir X-1	1.20				
Crab PSR	3.98	$4.24 \cdot 10^{37}$	$1.3 \cdot 10^{38}$	$1.0 \cdot 10^{39}$	$3.4 \cdot 10^{38}$
Cyg X-3	7.32	$2.36 \cdot 10^{39}$	$6.3 \cdot 10^{39}$	$8.5 \cdot 10^{40}$	$1.7 \cdot 10^{40}$
Her X-1	14.51	$9.67 \cdot 10^{38}$	$1.6 \cdot 10^{39}$	$4.9 \cdot 10^{39}$	$1.9 \cdot 10^{39}$
LMC X-4	1.75	$9.05 \cdot 10^{39}$	$3.6 \cdot 10^{40}$	$2.5 \cdot 10^{41}$	
Sco X-1	3.09	$7.42 \cdot 10^{38}-$ $-8.24 \cdot 10^{36}$			
Vela X-1	1.63	$8.49 \cdot 10^{36}$	$4.0 \cdot 10^{37}$	$1.9 \cdot 10^{38}$	
1A0620	3.74				
2A1822	2.53				
3C273	3.24	$3.11 \cdot 10^{48}-$ $-7.00 \cdot 10^{48}$		$8.8 \cdot 10^{49}$	
AE Aqr	3.83	$2.87 \cdot 10^{34}$			
Cen A	1.72	$8.90 \cdot 10^{43}$		$2.5 \cdot 10^{45}$	
Cyg X-1	5.56				
Gal.Cen.	2.29	$6.11 \cdot 10^{38}$	$3.1 \cdot 10^{39}$	$1.1 \cdot 10^{40}$	
LMC X-3	1.37	$1.11 \cdot 10^{40}$			
Rho Ophi	2.23	$1.52 \cdot 10^{35}$			
SN 1987a	2.73	$1.82 \cdot 10^{40}$	$8.2 \cdot 10^{40}$		$2.8 \cdot 10^{43}$
SMC X-1	3.19	$3.60 \cdot 10^{40}$			

In HE 5.1.4 the possible production of an intense ultraenergetic $\nu-$flux from Active Galactic Nuclei has been discussed. The protons accelerated by the accretion disk shock close to the black hole interact with the intense surrounding photon field giving rise to resonance production and consequently to ν's from π decay

$$p + \gamma \rightarrow \Delta \rightarrow n + \pi^+ \quad \rightarrow \nu_\mu + ...$$

The predicted fluxes [Fig. 8] still compatible with the present limits (HE 5.1.14) will be detectable with a neutrino telescope of $\sim 10^4 m^2$ surface .

Concerning the future detectors two classes of telescopes have been discussed: the deep underwater/ice and the surface ones.
The deep detectors have the advantage of a reduced background of downgoing cosmic ray muons. Their major disadvantages include the requirement of dealing with a difficult environment and a remote location.

The surface experiments have to distinguish the upgoing muons from the much more intense downgoing muon flux with a rejection power of $\sim 10^{11}$. The following projects have been presented:

- HE 5.3.4 (DUMAND). It consists in a water Cerenkov array to be deplayed on the Pacific Ocean bottom 30 kilometers off the island of Hawai at a depth of 4700 meters.
  The Cerenkov light is seen by 16–inch hemispherical photomultipliers arranged on nine vertical strings [Fig. 9]. The first three strings should be operating by the end '92.
- HE 5.3.2 (AMANDA). The approach is similar to that of DUMAND but placing the photomultipliers in the polar ice cap.
  Tests to measure the ice transparency are under way.
- HE 5.3.12 (GRANDE). A large area ($60.000 m^2$) water Cerenkov detector is proposed located in a water-filled excavation.
  Tests are under way to demonstrate its feasibility.
- HE 5.3.16 (SINGAO). This telescope should be performed by several planes of Resistive Plate Chambers using time of flight to identify the versus of the detected muons. Preliminary experimental results show that the rejection power of 10^{-11} is achievable with this approach.
- HE 5.3.11 (RAMANDA). The possibilities and the limitations of radio detections of neutrinos have been discussed.

4 Conclusions

The large number of contributions presented on the subject of my talk is the best indication of the great amount of work going on in the search for exotic particles as well as in neutrino astronomy.
With respect to the search for exotica in several cases the expected dark matter density suggests a clear goal for the sensitivity of the experiments . In these conditions also negative results turn out to be very important because they restrict the possible candidates for the solution of the dark matter problem.
In the so-called "μ-Astronomy" no steady or modulated source has been firmly identified. The problem of sporadic emission is open .
Concerning ν-Astronomy the present generation of running experiments are adequate for a high statistics detection of a neutrino burst created in a S.N. explosion eventually occurring in our Galaxy. The VHE, UHE ν-Astronomy is at the moment in a phase of theoretical and technical study in order to understand the size and the characteristics of a telescope capable to identify potential sources.
At this regard the high energy photon ($E_\gamma \geq 100 TeV$) fluxes observed few years ago from known sources (Cygnus X-3, Vela X-1, etc.) were expected to be correlated with high energy neutrino fluxes detectable with telescopes $\approx 10^3 - 10^4 m^2$ area.

The lack of confirmation of such photon fluxes makes more uncertain the size of the telescopes that may reveal possible point sources.
One has never to forget however that several phenomena of extreme interest can give rise to high energy neutrinos not accompanied by a photon flux: a good example discussed in this conference is the neutralino annihilation in the sun.
Perhaps a very large ($10^5 - 10^6 m^2$) detector will be needed to begin in a systematic way high energy neutrino astronomy.
A large common effort is needed to achieve this goal.
The activity full of ideas and enthusiasm centered around this subject is the best warranty that this effort will be succesfull.

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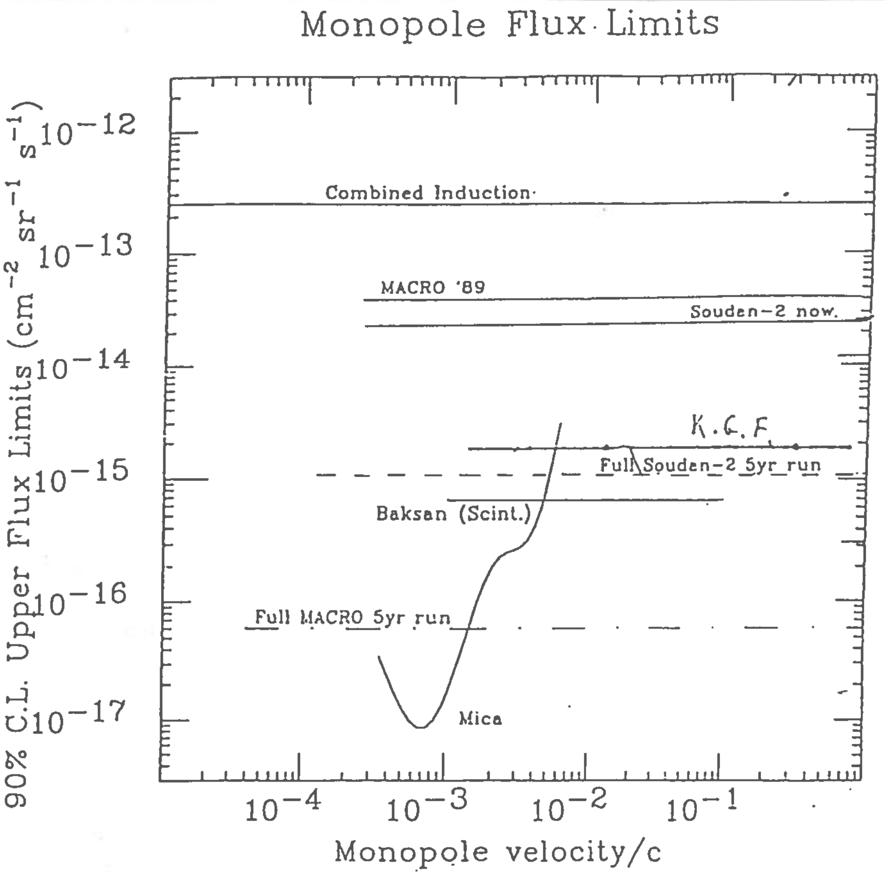

Fig.1 Monopole flux limits as a function of β.

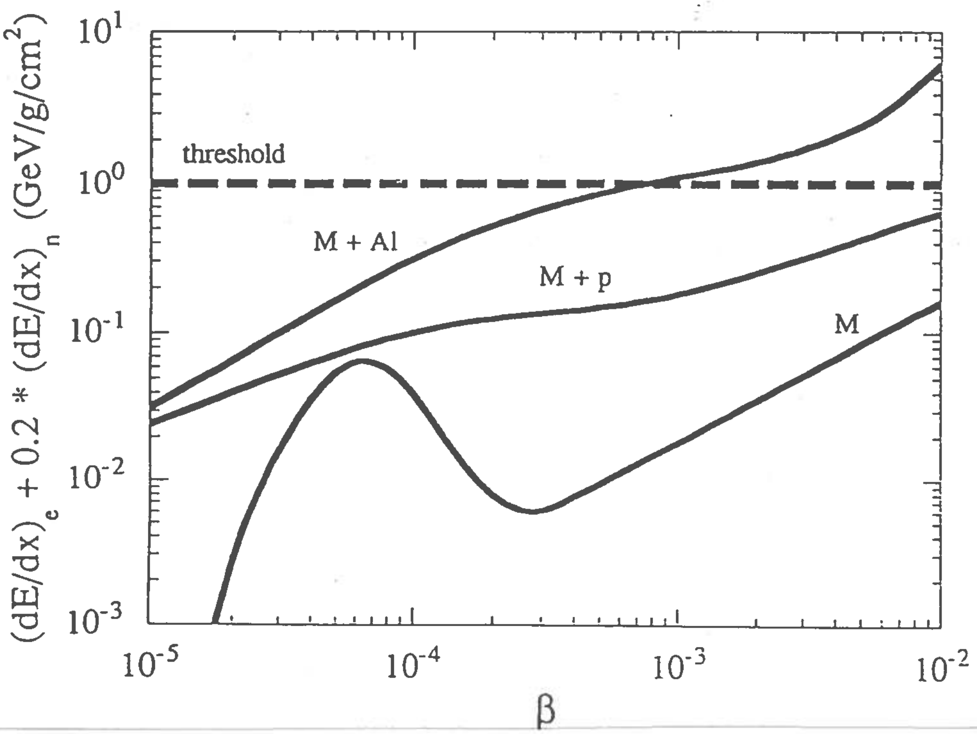

Fig.2 $\left(\frac{dE}{dX}\right) vs\beta$ for a monopole M, a monopole bound to a proton (M+p) and a monopole bound to an aluminium atom ($M + Al$). The threshold at 1 GeV/g/cm^2 makes it impossible to observe bare monopoles or monopoles bound to protons for velocities $\beta < 10^{-2}$.

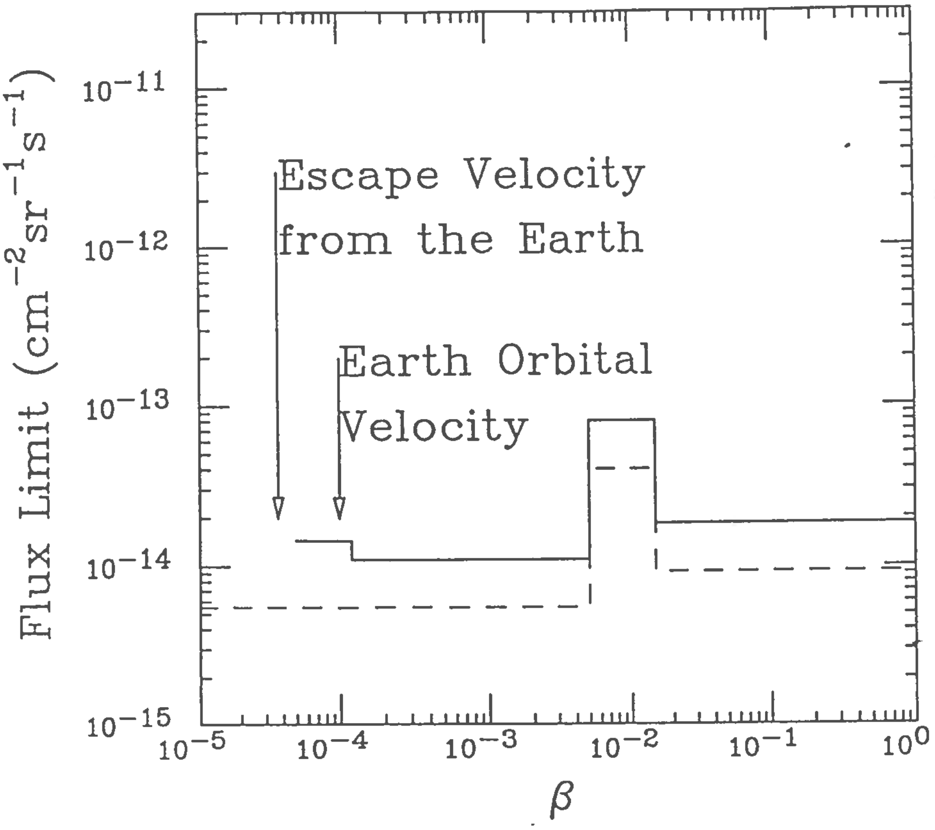

Fig.3 Nuclearite flux limit as a function of β from the combined MACRO searches. Solid line is for nuclearites heavier than 10^{-11} g but smaller than 0.1 g (able to penetrate to the MACRO depth but not able to penetrate the whole Earth). The dashed line is for nuclearites that can penetrate the whole Earth.

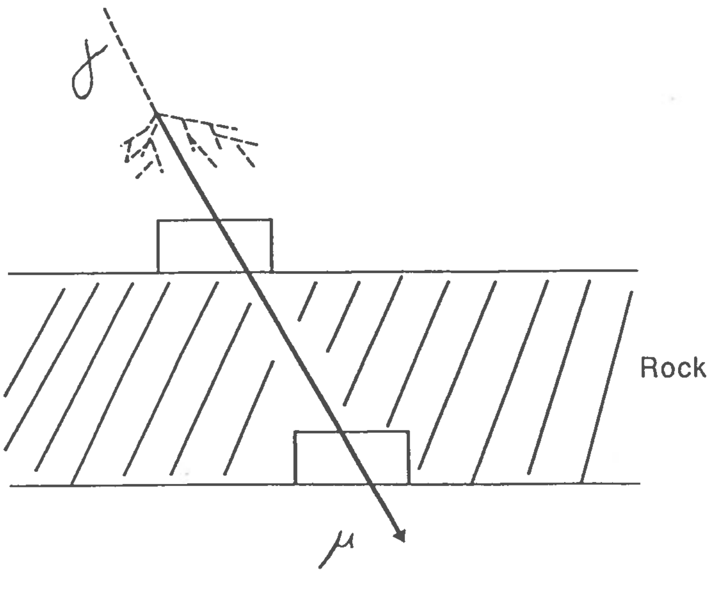

Fig.4 Schematic view of μ−astronomy experiments

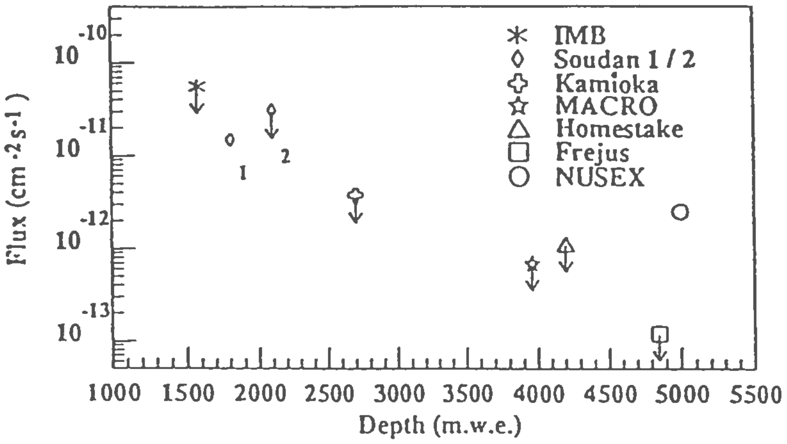

Fig.5 Measurements of the modulated flux from Cyg X3

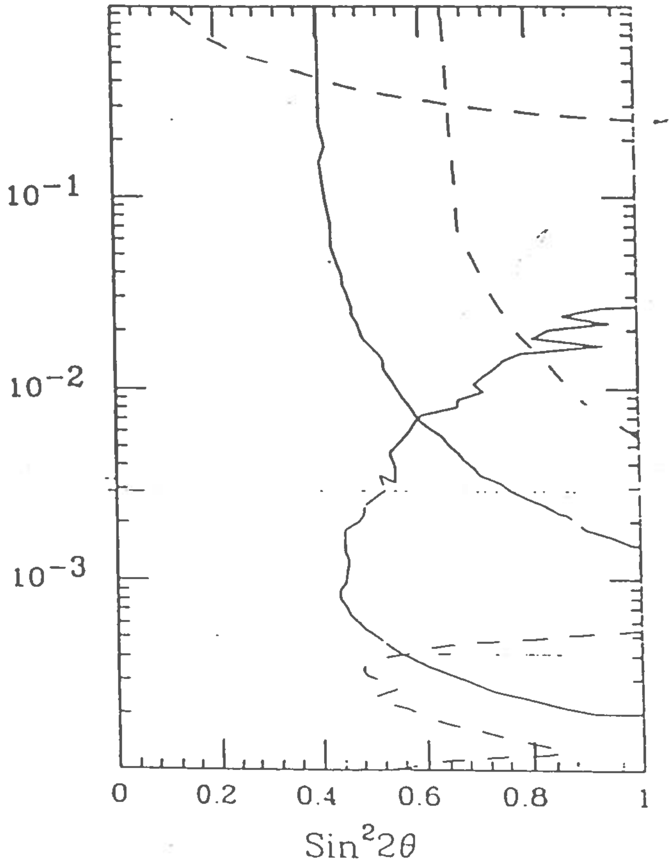

Fig.6 90% c.l. limits on $\nu_\mu \rightarrow \nu_\tau$ oscillations from rate (upper solid curve) and stopping fraction (lower solid curve) Dashed curves show limits from other experiments.

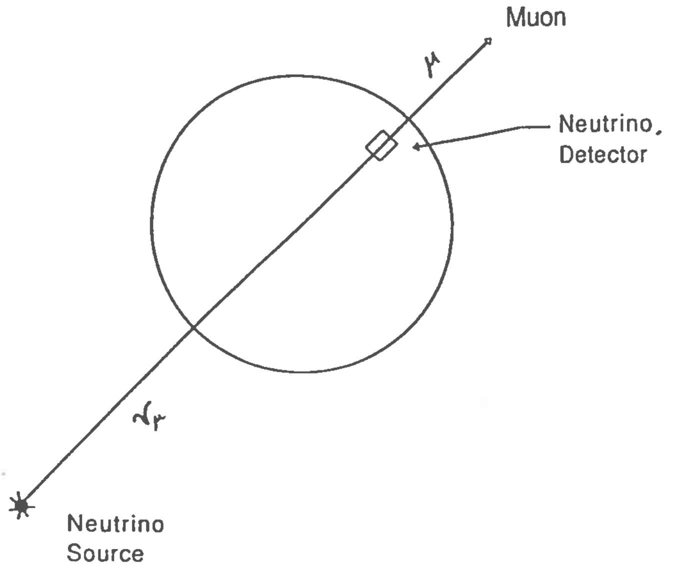

Fig.7 A schematic view of the detection technique for extraterrestrial neutrino.

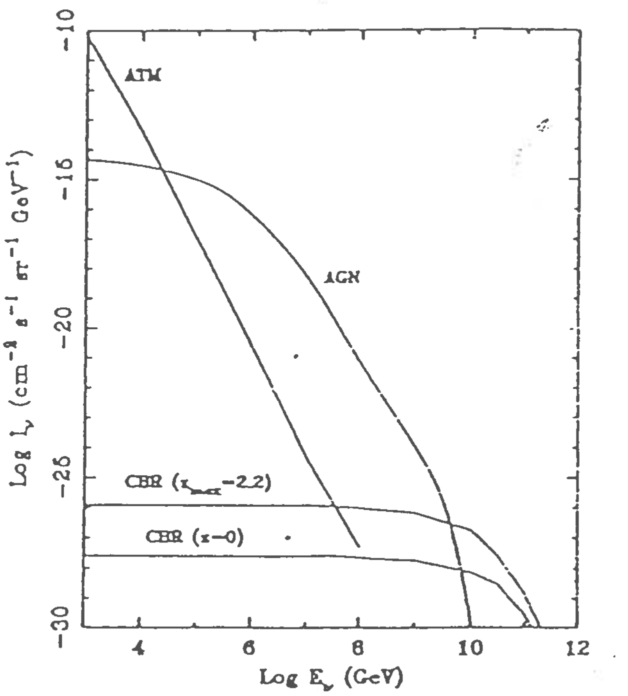

Fig.8 The integrate high energy $\nu_\mu(\bar{\nu}_\mu)$ neutrino background from AGN. Also shown is the horizontal flux from high energy cosmic rays interacting with the Earth's atmosphere (ATM) and the background expected from photomeson production of the extragalactic high energy cosmic rays with the cosmic background radiation (CBR).

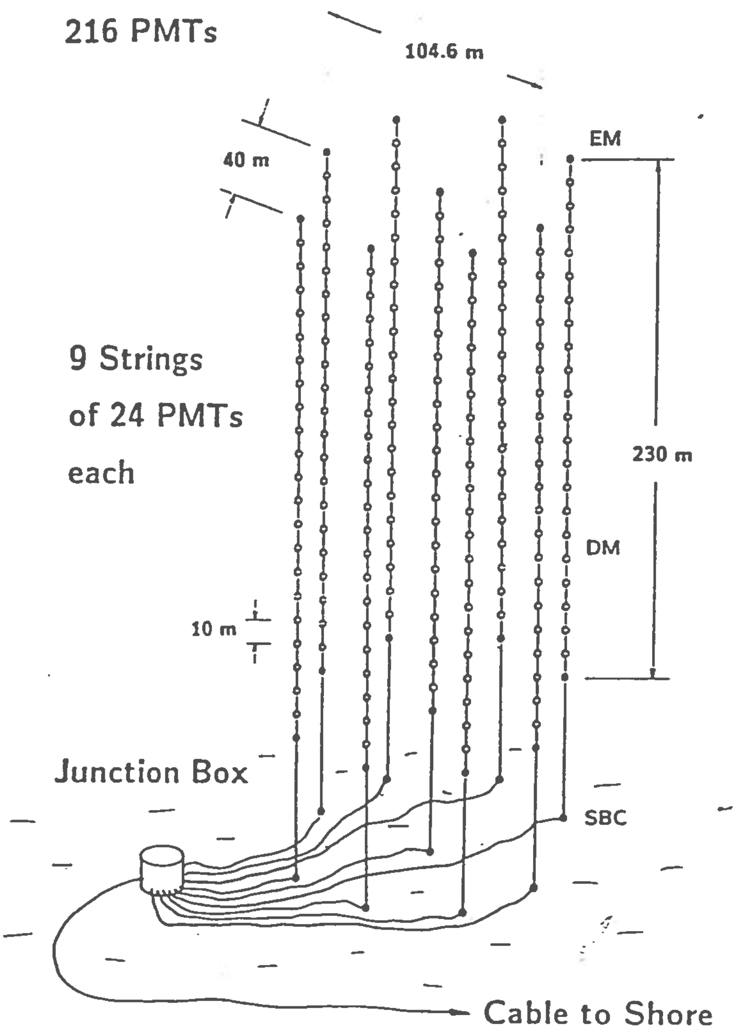

Fig.9 Configuration of the DUMAND II array.