ATMOSPHERIC ν EXPERIMENTS

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ABSTRACT

In this report the most recent results on Atmospheric neutrinos are reported. In particular the Soudan 2 and Macro experiment are reviewed. The interest for future experiments is investigated and the Monolith project is considered in a more detailed way.

1. Recent results

The most important results come clearly from the SUPER-KAMIOKANDE collaboration.Their results were reported in the same Conference by C. McGrew. In this paper I will report on interesting confirmations and new data from the Soudan 2 and Macro Collaboration.

1.1. Soudan 2

The Soudan 2 Detector is a fine-grained iron tracking calorimeter, working since April 1989 in the Soudan Mine Underground State Park-Minnesota.
The basic detector is a slow-drift time projection chamber.
These detectors are assembled with mylar sheets interlived with corrugated steel sheets with an honeycomb geometry.One module has a mass 4.3 tons and the total mass is $\simeq$ 1. Kton.
The calorimeter is surrounded by a double-layer of proportional tubes acting as an Active Shield of $1700m^2$ used as veto .
The Detector has a very good tracking and a very good separation of ν_μ and ν_e CC events.
The background from inelastic interactions of cosmic ray muons with nuclei of the rock is strongly reduced by the use of the veto.
The selected events are classified as Gold Events if they are fully Contained and they have zero associated hits in the shield.
The residual background due to neutral particles coming from the rock is subtracted and the events are classified as tracks events (ν_μ) and showers events (ν_e).
The neutrino flavor ratio-of-ratios is measured :

$$R = ((tracks/showers)_{data}/(tracks/showers)_{MC}) = 0.68 \pm 0.11(stat.) \pm 006(syst.) \quad (1)$$

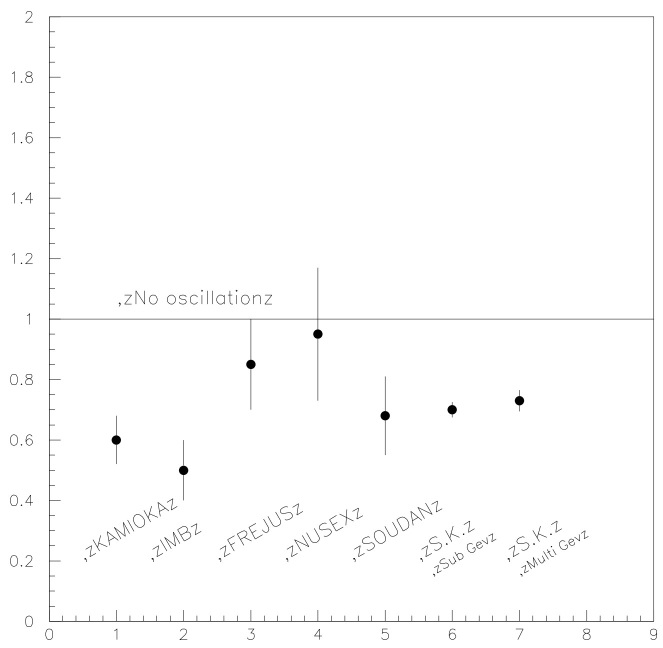

Figure 1: R measurements

In Fig.1 the Soudan 2 result is shown and compared with other existing data.

Quantity	ν_μ CC	ν_e CC
$\Delta E/E$	20 %	23 %
Angle	33.2°	21.3°
$\Delta(Log(L/E))$	0.49	0.43

Table 1: Resolutions in Soudan 2

The angular distribution of the events is shown in Fig.2(Left); it is clear the good agreement between data and Monte-Carlo in absence of oscillations for the ν_e CC and a clear discrepancy for the ν_μ CC events.
In the two neutrino scenario the important physical quantity is L/E (L= pathlength, E= ν energy) ; to increase the resolution in L/E they have selected a sample of High Resolution events (Quasi elastic Tracks and Showers events and Multiprong events with suitable kinematics cuts). The corresponding resolutions are shown in Table 1.

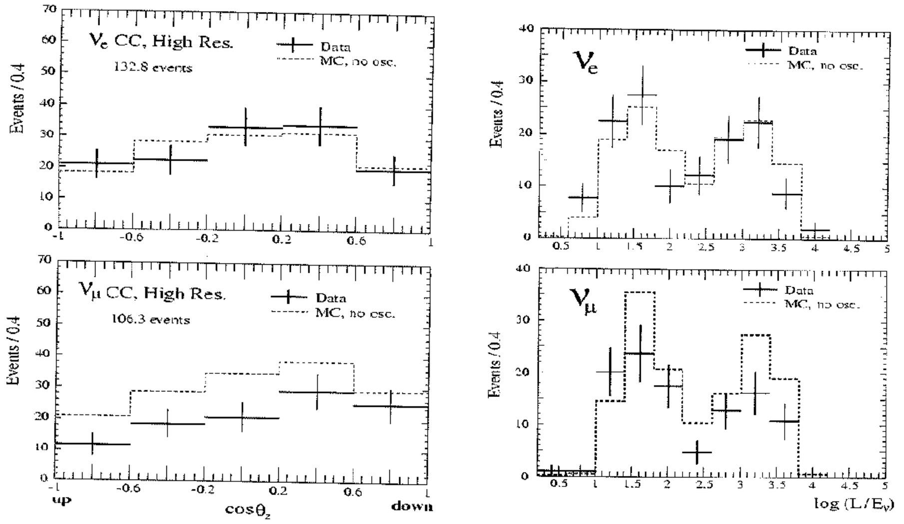

Figure 2: Left: Soudan 2-Angular Distributions. Right:Soudan 2-L/E Distributions(no oscillation)

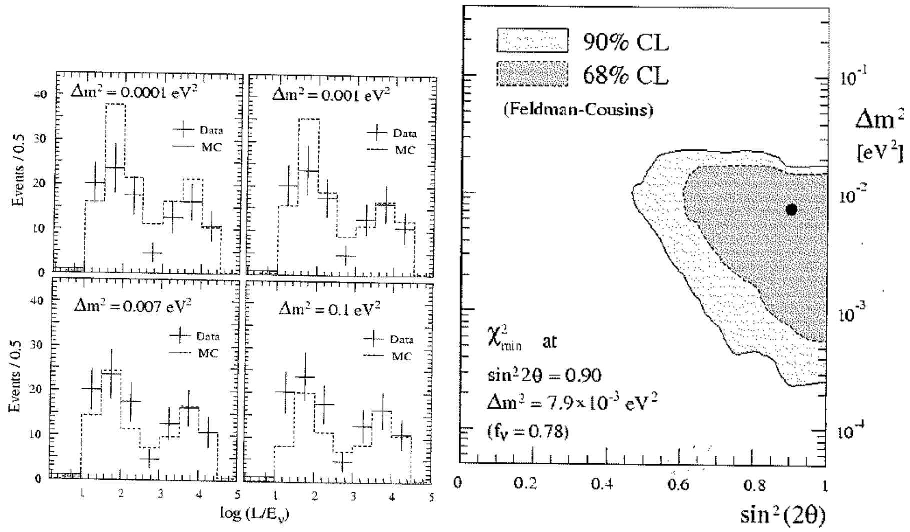

Figure 3: Left:Soudan 2-L/E Distributions(maximum mixing).Right:Confidence Level regions

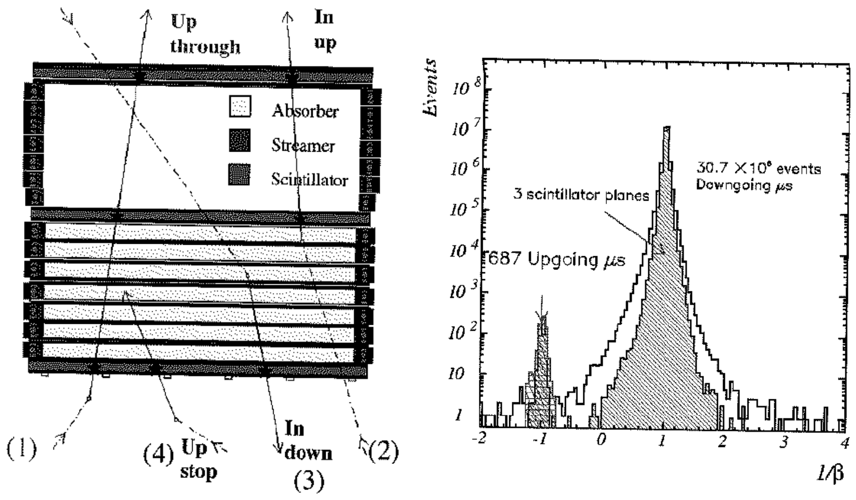

Figure 4: Left:Neutrino event topologies in MACRO.Right:Upward Going muons-$1/\beta$ distribution

In Fig.2(Right) and in Fig.3(Left) the comparison between the events distribution and the MC in the hypothesis of no oscillation and oscillations with different parameters are displayed.
Finally the Confidence Level Regions from the Soudan 2 experiment are shown in Fig.3(Right)

1.2. MACRO

The Main feature of Macro [1)] are :
-Large acceptance ($10000 m^2 sr$ for an isotropic flux)
-Low downgoing μ rate :10^{-6} of the surface rate
-600 tons of liquid scintillator to measure T.O.F. (time resolution 500 psec)
-$20000 m^2$ of streamer tubes (3 cm cells) for tracking with angular resolution $< 1°$
The selected events belong to three categories :
a) Up throughgoing μ (with the opportunity to use the T.O.F.)
b)Internal Upgoing μ (with the opportunity to use the T.O.F.)
c)Internal Downgoing μ and Upgoing stopping μ (withouth the possiblility to use the T.O.F.)
The Macro Detector and a sketch of events of the three catogories are displayed in Fig.4(Left).

The most interesting results are obtained from the Up-throughgoing μ.
These events are well separated from the downgoing ones by using the Time of Flight measurements (see Fig. 4-Right).

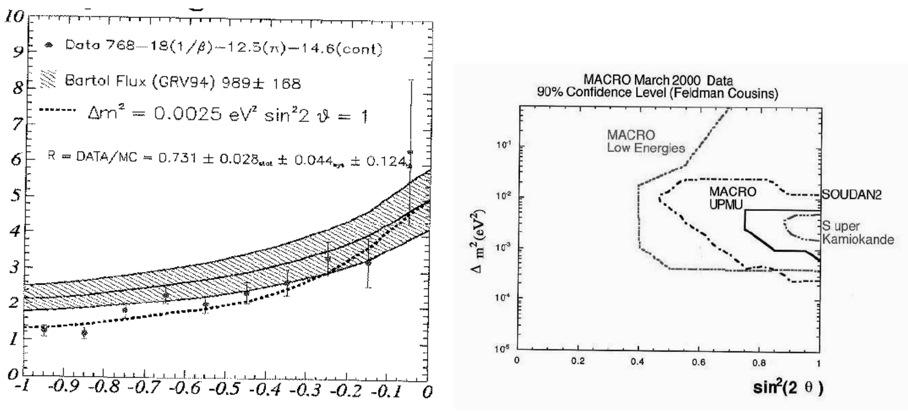

Figure 5: Left:Upward Going Muons (Through)-Angular Distribution.Right:Confidence level regions-$\nu_\mu \Rightarrow \nu_\tau$

A detailed M.C. calculation [2] was used to compare the data to the predictions in absence of oscillations and the result is :

$$R = data/prediction = 0.731 \pm 0.028(stat.) \pm 0.044(syst.) \pm 0.124(theoret.) \quad (2)$$

The angular distribution (see Fig.5-Left) was analysed in terms of the no oscillation and $\nu_\mu \Rightarrow \nu_\tau$ oscillation hypothesis and the corresponding χ^2 yields to the probabilities:

$P = 0.9\%$ (no- oscillation)
$P = 26\%$(oscillation with maximum mixing and $\Delta m^2 \simeq 0.0025eV^2$).
The total number of events and the angular distributions were also analysed in term of the two hypothesis :
$\nu_\mu \Rightarrow \nu_\tau$ and $\nu_\mu \Rightarrow \nu_{sterile}$
The first hypothesis is favored (Probability= 57 %) in comparison with the second one (Probability=14.5 %).
A more sensitive analysis was performed by using the ratio of the vertical to horizontal events:

$$R = N(cos(\theta) < -0.7)/N(cos(\theta) > -0.4) \quad (3)$$

In this way the $\nu_{sterile}$ against the ν_τ hypothesis is disfavored at$> 98\%$ for any mixing. All these results agree very well with the Super-Kamiokande data. In the Fig.5(Right) the Confidence level regions of SK , Soudan 2 and Macro are displayed.

2. Future experiments

Why new atmospheric neutrino experiments?
I will try to report my personal feeling on this subject.
This kind of experiments can profit of the following advantages:
-A large L/E range : in table 2 a comparison is made with the Long Base Line experiment in progress or in construction.
If the value of $\Delta m^2 = 0.0025 eV^2$ will be confirmed or new measurements will indicate a lower value , it should be very hard for the L.B.L. experiments to observe the first minimum or the second maximum of the oscillation pattern ($\Delta = 1.$ or $\Delta = 2.$) This opportunity, in that case, is reserved to the atmospheric neutrino experiments.
-The use of the same Detector and two sources (Down and Up-going ν)
-The possibility to study Matter Effects (L up to 13.000 Km)

Experiment	$\simeq (L/E) range (Km/Gev)$	$\Delta = \Delta m^2 \times L/(2. \times \pi \times E)$
K2K	100.-1000.	0.1-1.2
MINOS	18.-730.	0.02-0.9
CNGS	7.-185.	0.009-0.25
ATMOSPHERIC	0.7-30000.	0.0008-38.

Table 2: Range of L/E and Δ in the hypotesis of $\Delta m^2 = 0.0025 eV^2$

2.1. Future Detectors

The detectors must have two important features:
-Large Mass (at least comparable with S.K.)
-Very good L/E resolution (better than S.K.)
This second requirement is very important ; indeed ,in absence of observation of the typical swing of the oscillation pattern , the oscillation phenomenon is not completely proved and other physical hypothesis (like Decay or Decoherence etc.) can survive. In the Fig.7 the oscillation pattern for $\Delta m^2 = 0.0025 eV^2$ is reported (continous line) and it is compared with the results that can be obtained in the hypothesis of experiments with resolutions similar to the S.K. experiment (dashed line) and with better resolutions similar to the Monolith project (dotted line). It is clear that better resolutions are very important to discriminate the oscillation from other hypotesis.

Two kinds of detectors are proposed :
a) with mass $M >> M_{Super-Kamiokande}$

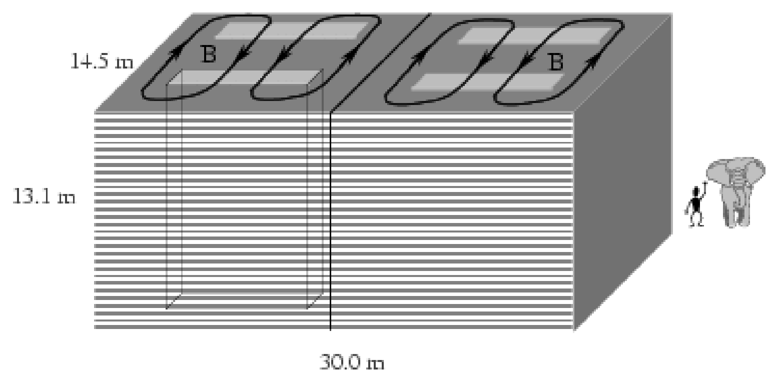

Figure 6: The Monolith Detector

b) with mass $M \simeq M_{S.K.}$ but with better resolution in L/E
Class a) Detectors are The Megaton water Cerenkov Detectors [3]
Class b) Detectors are Super-Icarus [4],Nice[5],Monolith [6]

2.2. Monolith

I will describe the Monolith Project as an example of the class b) Detectors. Monolith is a Magnetized Fe spectrometer ($B \simeq 1.2$ Tesla) shown in Fig. 6 with a mass of 35 Ktons

It is constituted by a sandwich of Fe slabs interspaced with Glass Spark Counters (GSC)[7] ;the total area of the sensitive detectors is 52.000 m^2; the detector should be placed in the Gran Sasso Laboratory.
The Physics goals of the experiments are:
-Prove the ν oscillation hypothesis through the observation of the oscillation pattern (see Fig.8).
-Improve the measurement of the parameters $\Delta m^2, (\sin(2 \times \theta))^2$ (if oscillations).
-Measure the admixture of $\nu_{sterile} - \nu_e$ searching for matter induced effects.
In four years of running Monolith can show the full oscillation swing(see Fig.8).

-In Fig.9 the sensitivity of this experiment to the oscillations parameters is shown and compared with SuperKamiokande.

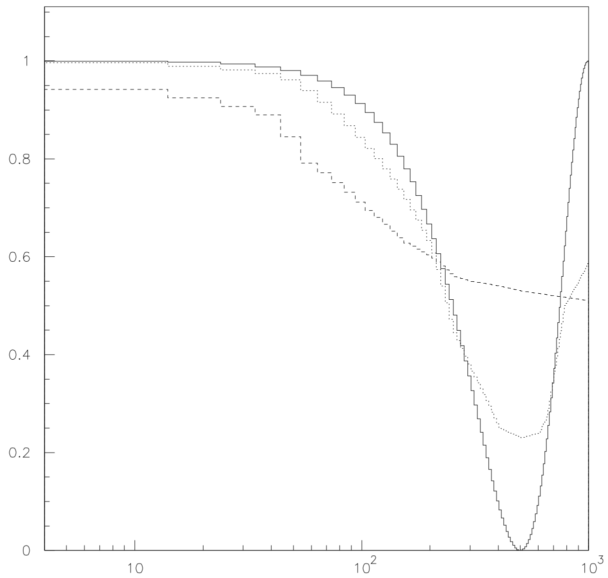

Figure 7: Oscillation smeared by detector resolution. Survival Probability versus L/E(Km/Gev)

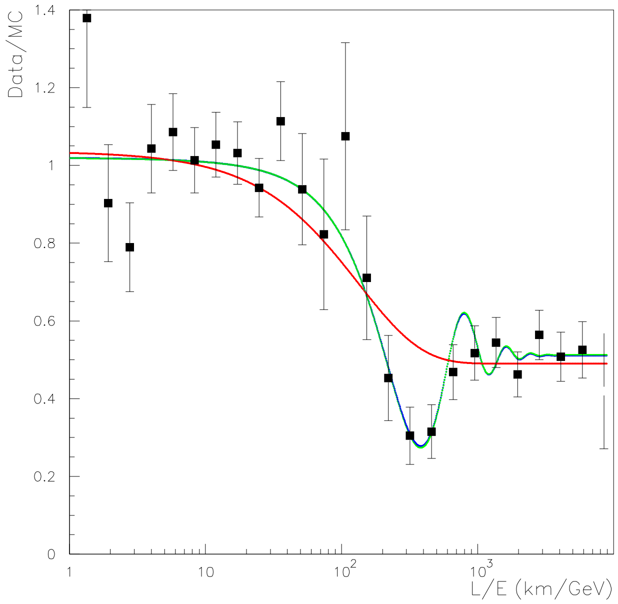

Figure 8: Simulated results of Monolith in 4 years of running.Dashed line=oscillations hypothesis with $\Delta m^2 = 0.003 eV^2$.Continuos line=decay hypothesis

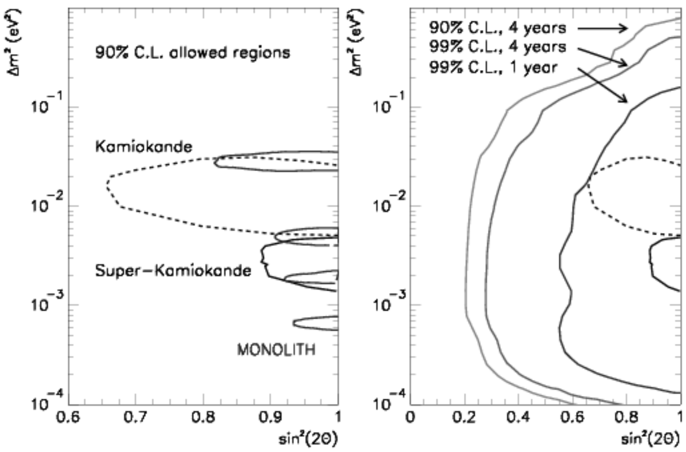

Figure 9: Sensitivity of Monolith to the oscillation parameters.Left:expected allowed regions in four years of running for four values of $\Delta m^2 (0.7, 2., 5., 30.) \times 10^{-3} eV^2$.Right: Monolith exclusion curves

3. Conclusions

In conclusion I would like to remark three points:
- Important confirmations of the SuperKamiokande effect , are obtained by Soudan 2 and Macro experiments , with completely different experimental techniques.
-New experiments on the atmospheric neutrinos are very usefull both to confirm the oscillation hypothesis , both to measure the oscillation parameters (if any).
Furthermore these experiments are very sensitive to matter effects.
These arguments are made stronger if the value of Δm^2 is $\leq 2.5 \times 10^{-3} eV^2$
-New Detectors must have large mass and very good resolution on the L/E parameter; a good example is the Monolith proposal.

4. References

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