F Ronga

Neutrino Physics with the MACRO detector

• MACRO is a detector in the underground Gran Sasso Laboratory (Italy)

Monopole Astrophysics Cosmic Ray Observatory

Collaboration between several USA-Italy institutions
Active elements : liquid scintillators and streamer tubes
Dimension 72*12*9 m^3

Overview

1) Atmospheric Neutrino Oscillations

2) Results on the Upward Muons produced from neutrino interactions in the rock below the MACRO detector (lower part)

3) Run with the full MACRO detector

Not included in the talk :

Search for neutrino astrophysical point sources
Search for neutrino from WIMPS in the SUN or in the Earth core

Atmospheric Neutrinos

- **Produced from the cosmic ray cascade in the atmosphere**
- **decay chain π (or K) $\rightarrow \mu + \nu_\mu$, $\mu \rightarrow e + \nu_\mu + \nu_e$**
- **The ratio ν_e / ν_μ in the atmosphere should be approximately 1/2 for low energy (~1 Gev) "contained events"**
- **Detailed Calculation : $R_{e/\mu}$ = .49 ±.01**

Barr et al Phys Rev D39 (1989)
Honda et al Phys Lett B 248 (1990)
Lee and Koh Nuovo Cim B 105 (1990)
Bugaev , Naumov Phys Lett B232 (1989)
Perkins Astropart. Phys.

- **Experiments : measurement of**

R = Error!

KAMIOKANDE	**$.6^{+.07}_{-.05}$ ±.05 (syst)**
IMB	**.54 ± .02 ± .07**
SOUDAN2	**.69 ±.19±.09**
FREJUS (198	**.87 ± .13**
FREJUS(1995)	
NUSEX	**.99 ± .40**

Atmospheric Neutrinos

• Proposed solutions to the contained event puzzle :

neutrino oscillations
proton decay ($p \rightarrow e + \nu + \underline{\nu}$)
excess in the ν_e events due to neutron background

• Second puzzle (1994) :

KAMIOKANDE MULTI-GEV events

1) The deficit is present also in the partially contained events (higher energy events)

$$R = .57^{+.08}_{-.07} \pm .07$$

2) The angular distribution of the ratio is not flat

• Claim : oscillations with

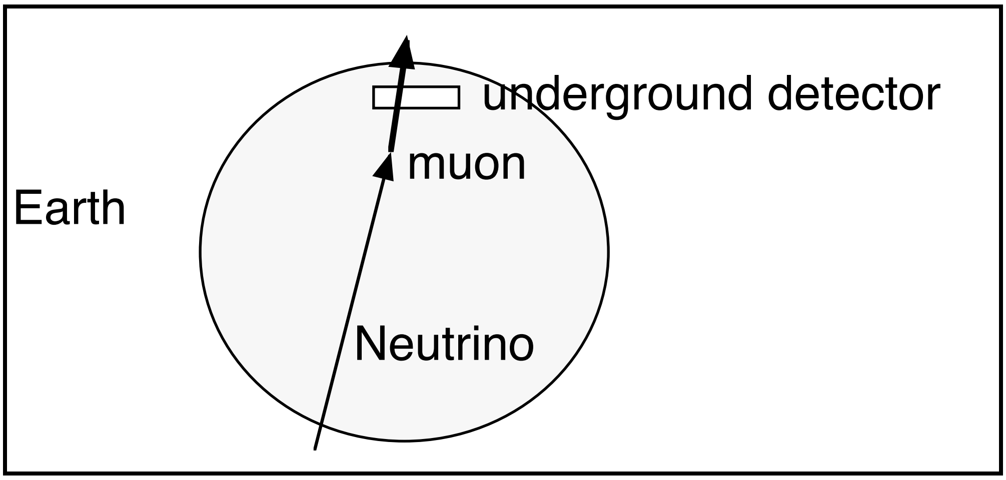
$$\delta\, m^2 \sim .01\ ev^2$$
$$Sin^2\ (2\,\Theta) \sim 1.$$

• due to the incertitude of the absolutes fluxes is not possible to discriminate between the hypothesis:

a) ν_μ deficit (oscillation $\nu_\mu \leftrightarrow \nu_\tau$) (slightly preferred)

b) ν_e excess (oscillation $\nu_\mu \leftrightarrow \nu_e$)

UPWARD- GOING MUONS



• Typical distance for neutrinos producing upward-going muons below the detector ~10000 Km

• <u>IF</u> oscillations are true:

$$P(\nu_\mu \rightarrow \nu_\tau) = \sin^2(2\Theta) * \sin^2(1.27\ \delta m^2\ L/E) =$$

L km, E Gev

$$= \sin^2(1.27 * .01 * 10000/E)$$

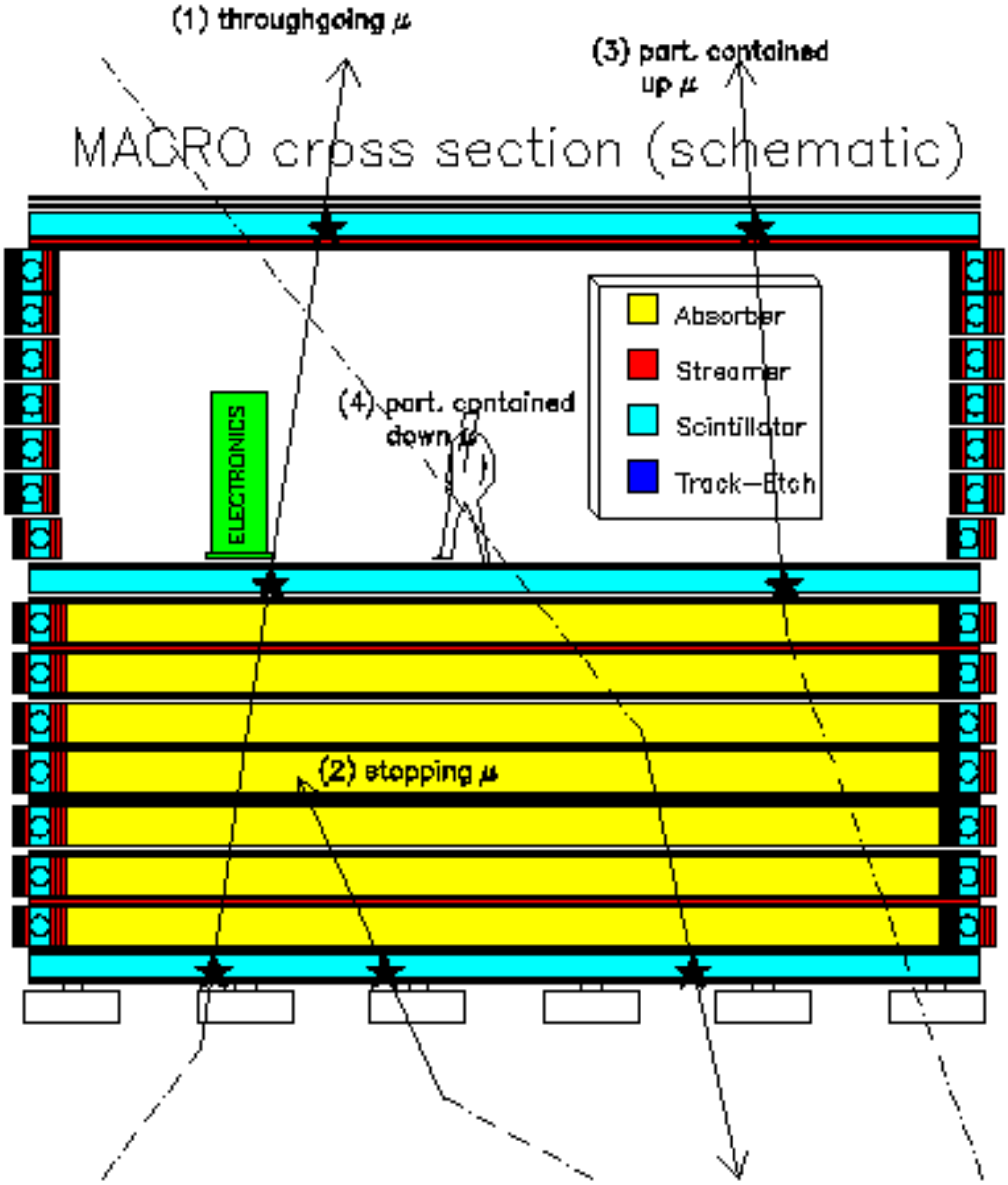
The first node (maximum oscillation) is at E ~ 81 Gev , near the median value of the energy of the atmospheric neutrinos for this category of events

Very clean sample (no low energy effects, no multiprong effects)

===>>> Importance of this measurement

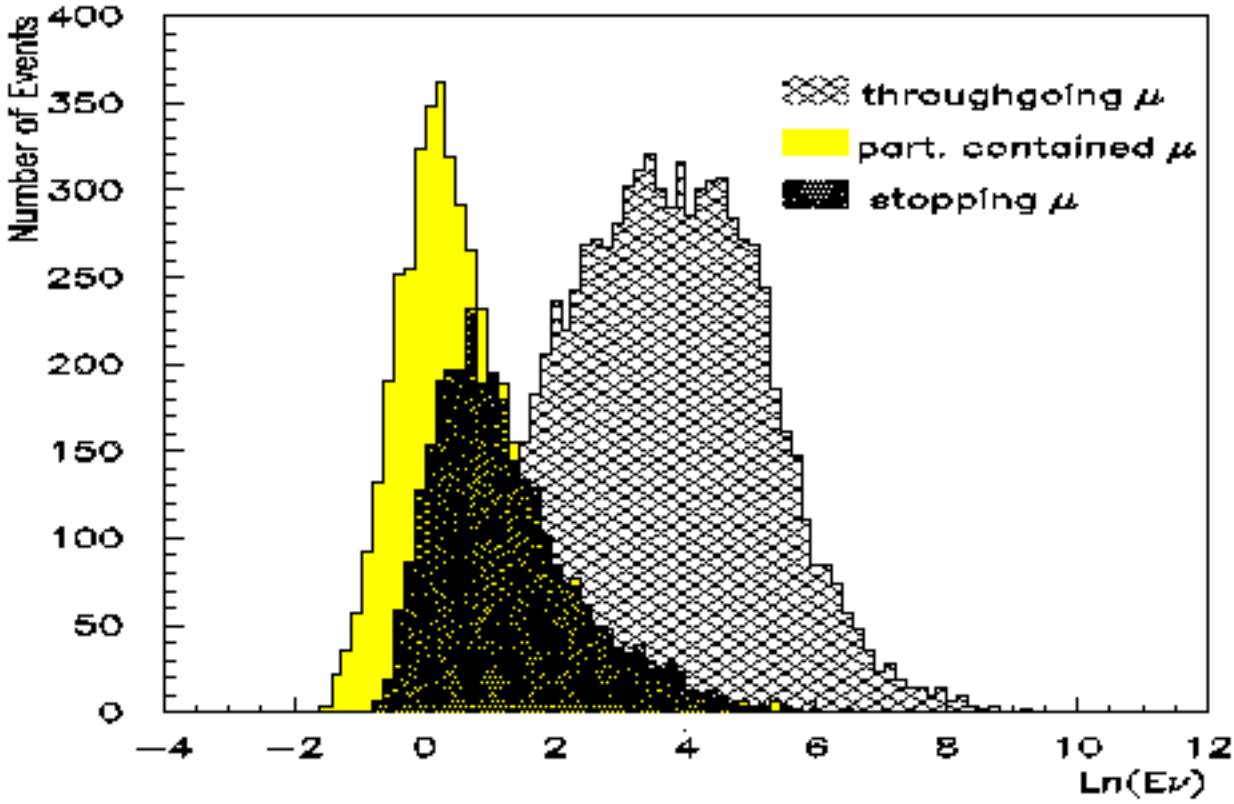
UPWARD- GOING MUONS IN MACRO

• **MACRO could detect different categories of Neutrino produced Muons.**



UPWARD- GOING MUONS IN MACRO

• Different thresholds for the muon energy and therefore different parent neutrino spectra ==>> different oscillation parameters.



UPWARD- GOING MUONS IN MACRO

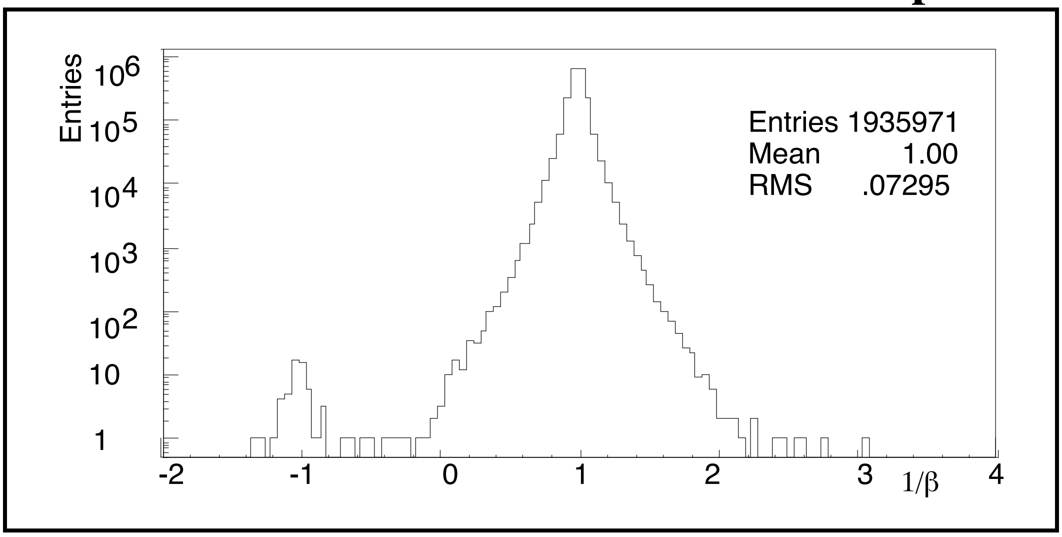
• The analysis is based on the time of flight separation between the downgoing muons and the neutrino produced upward-going muons. Rejection factor > 10^6

• In this analysis data taken during 1989-1993, only lower part of MACRO ==>> max. 2 counters for the time of flight, Threshold ~ 1 Gev

• Small background (due mainly to events with showers or events with many muons)

• No visual scanning necessary (as was in the previous experiments : Kamiokande, IMB, Baksan)

1/ Beta distribution for a data sample



UPWARD- GOING MUONS: RESULTS

• **MACRO data** 74 ± 9 (stat) ± 8 (systematic apparatus)

•"**Best prediction**" 101± 17 (systematic theoretical)

data/prediction	.73±.17 (errors in quadrature)

• Why so large errors in the predictions ?
The calculation of the prediction is based on

1)Bartol (Frati et al 1993) atmospheric neutrino flux
±13%
Constraints from the measurement of the muon flux with a balloon experiment (Mass-Wizard experiment)
before the error was ±20%

2) Deep inelastic neutrino cross section ±9%
Morfin - Thung fragmentation function (set S1).

• Recently the importance of the poorly known cross section at low energy has been discussed
Lipari, Lusignoli, Sartogo Roma preprint 1072-1994
They compute a 4% increase in the expected rate
Our evaluation of the errors includes our estimated incertitude in the low energy region

3) Muon energy loss in the rock ±5%

• Check with other calculations :

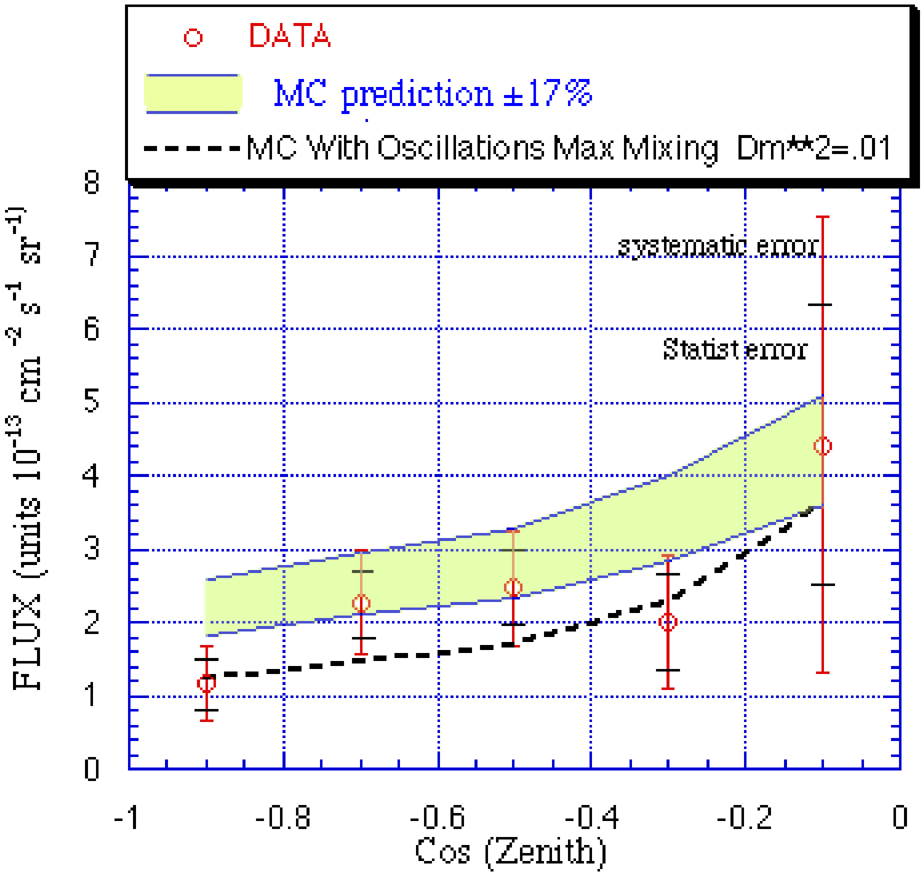
Volkova Flux /Bartol Flux .91

Butchevich Flux/Bartol Flux 1.026

UPWARD- GOING MUONS: Angular Distribution

• **The shape of the angular distribution is less sensitive to the theoretical calculations**

• **Most of the deficit should be in the bin near the vertical**



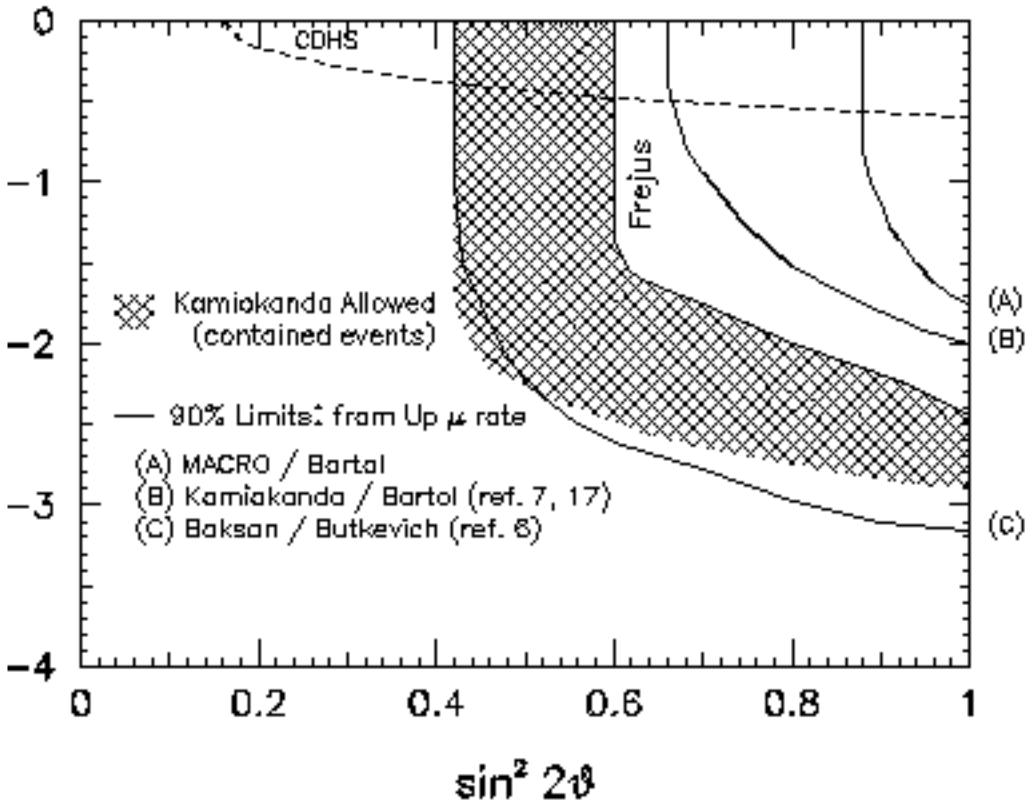
• **More statistics is necessary particularly in the bin near the horizontal. Full MACRO ==>> big increase in the acceptance near the horizontal. Results probably in 2 year**

EXCLUTION PLOT

• In the plot are shown previously published limits which are calculated under similar assumption to those used for the MACRO limit
(limits calculated with the neutrino Volkova flux are more restrictive)

• not shown the IMB limit from stopping/passing

• no lower bound (from MACRO) because data are consistent at 90% CL with no mixing



• Note : MACRO 1 Gev Threshold
Kamiokande 3 Gev Threshold
Disagreement with the Baksan limit?

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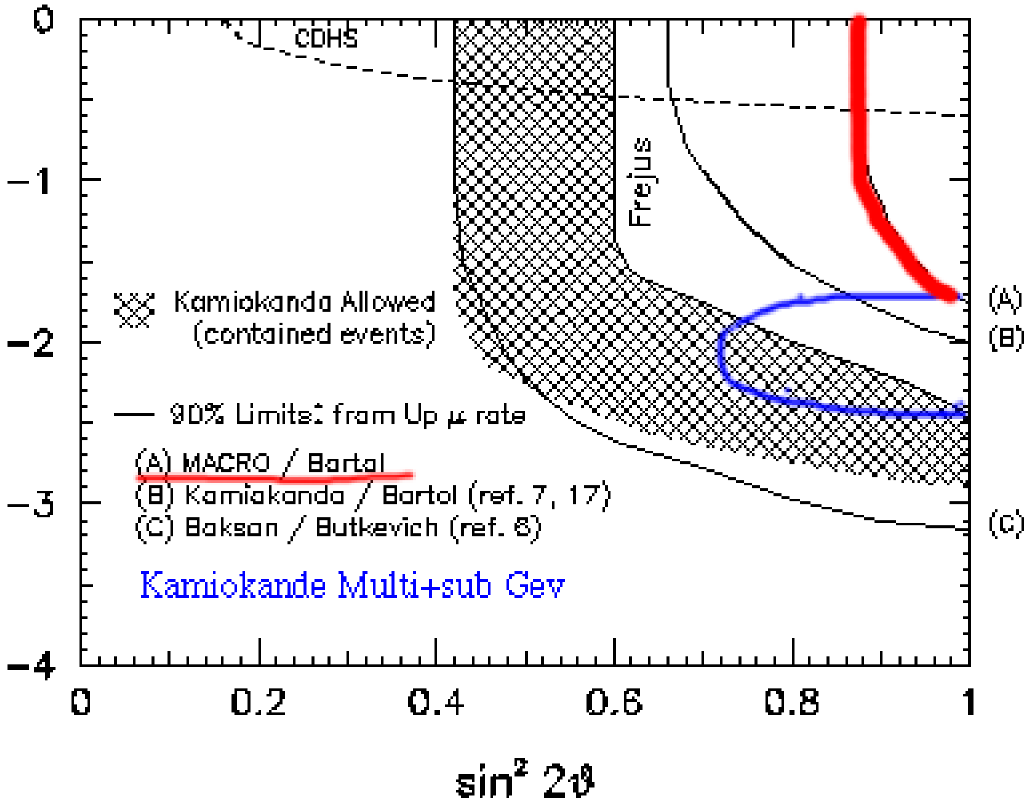

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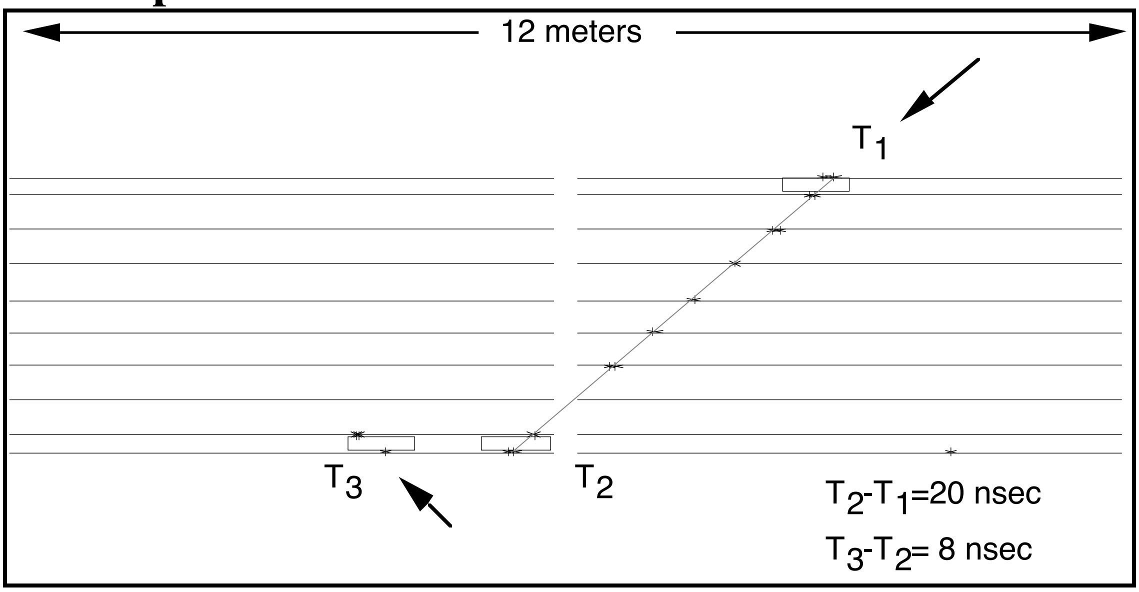
STOPPING MUONS

- Lower Neutrino Energy. Search for oscillations in the region of $\delta m^2 = .001$.
- Ratio passing/stopping less sensitive to the different models for the neutrino fluxes. Analysis in progress.

- Interesting background : pion back scattering from muon interaction in the rock around the detector
- Example



Run 6153 EV 5062 2-MAY-1993 22.39.58

- IF the muon doesn't intercept MACRO ==>> Stopping event candidate

- Not a big problem in MACRO (~ 10 % of the stopping muons, evaluated from a phenomenological MC). But what about the IMB experiment at a lower depth?
- Lipari et (1994) ~ 10% increase in the stopping /passing ratio

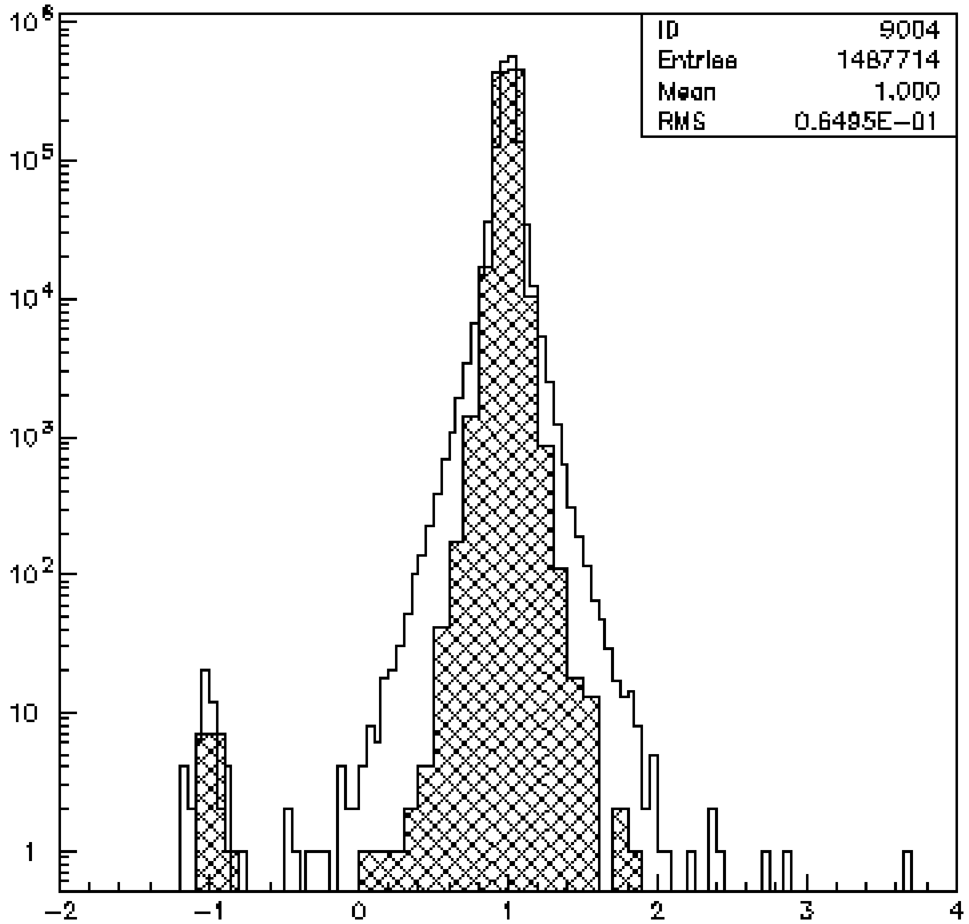
• Limits based on the stopping/passing analysis should be reinterpreted

FULL DETECTOR RUN

• Started June 1994

• better rejection of the downgoing muons :
  a) larger path length
  b) about 50% of tracks with 3 counters

• larger acceptance for near horizontal events

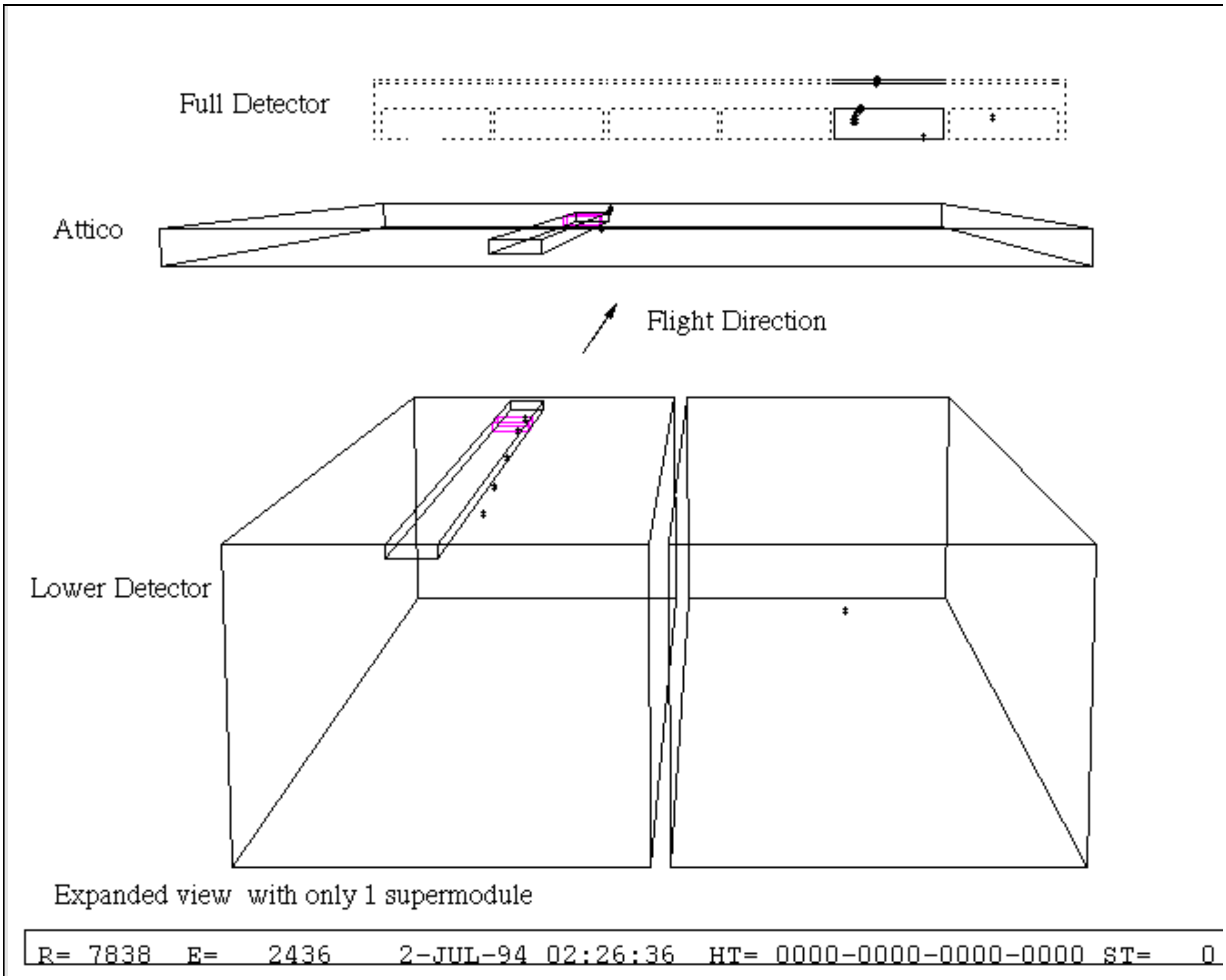


1/β distribution for the full detector run; dashed histogram : tracks with 3 scintillator counters

• 3 scintillator events : background free

FULL DETECTOR RUN

• more event topologies : in particular partially contained events with neutrino interaction inside the lower detector



Conclusions

• UPGOING muons in MACRO are very clean events :
no scanning necessary (as was in the past experiments)

• MACRO results on upgoing muons compatible with oscillations parameter as suggested from Kamiokande.
This is due to a small deficit observed

R= data/prediction	**.73±.17 (errors in quadrature)**

(but compatible also with the no oscillation solution).
Larger part of the error due to systematic incertitude in the flux calculation

• sligth discrepancy with the Baksan upgoing muon results

• FULL MACRO :
a) better data (background free)
b) larger acceptance for horizontal events
==>> study of the angular distribution
c) more event topologies

NEUTRINO ASTRONOMY

- small angle between neutrino and muons (~ 1 °)

- with the existing detectors is unlikely to detect signals from steady sources. Most likely are sources like Galactic yang supernova galactic remnants (a few events/1000 m^2 for ~ 1 year after the explosion)

• maximum signal (Gaisser at al 1994) :
From the cosmic ray spectra, assuming a Galactic production with a life-time $5*10^5$ year , total power to maintain the cosmic rays:

$$L = 10^{39} \text{ erg/sec}$$

If this power is divided between n sources the maximum signal from the nearest neighbour source is

$$3 \text{ ev year}/1000 \text{ m}^2/\text{year} \sim 10^{-14} \text{ cm}^{-2} \text{ sec}^{-1}$$

• Of course this is an extreme upper limit

• Very high energy muons are possible from neutrinos from AGN. Showers. Analysis for diffuse flux in progress

Neutralino Dark Matter from Earth and Sun

• Neutralino is predicted in the framework of the Minimal Supersymmetric extension of the Standard Model.
The mass is related to 3 parameters (M_2 , μ , $\tan\beta$).
To calculate rates assumptions are necessary on the masses of the Higgs bosons and of the sfermions

• Neutralino dark matter ==>>
capture from Earth or Sun
accumulation in a region around the center
pair annihilation gives neutrinos
neutrinos are detected via upward-going muons

• Rates are largely model dependent (several order of magnitude).

• We refer to the Bottino et al model (1994)
Torino preprint DFTT 34/94

• For the Sun the limits in the future could decrease linearly with the time (signal with an angular spread mass dependent of a few degree). For the Earth we are already background limited (signal with a spread of the order of 20°)