6-3-01 ν TELESCOPE 01

PULLIA

ATMOSPHERIC ν RESULTS

(≠ S.K.)

- Recent Results

-SOUDAN 2

-MACRO

- Future

-Why Atmospheric neutrinos?

-New Detectors

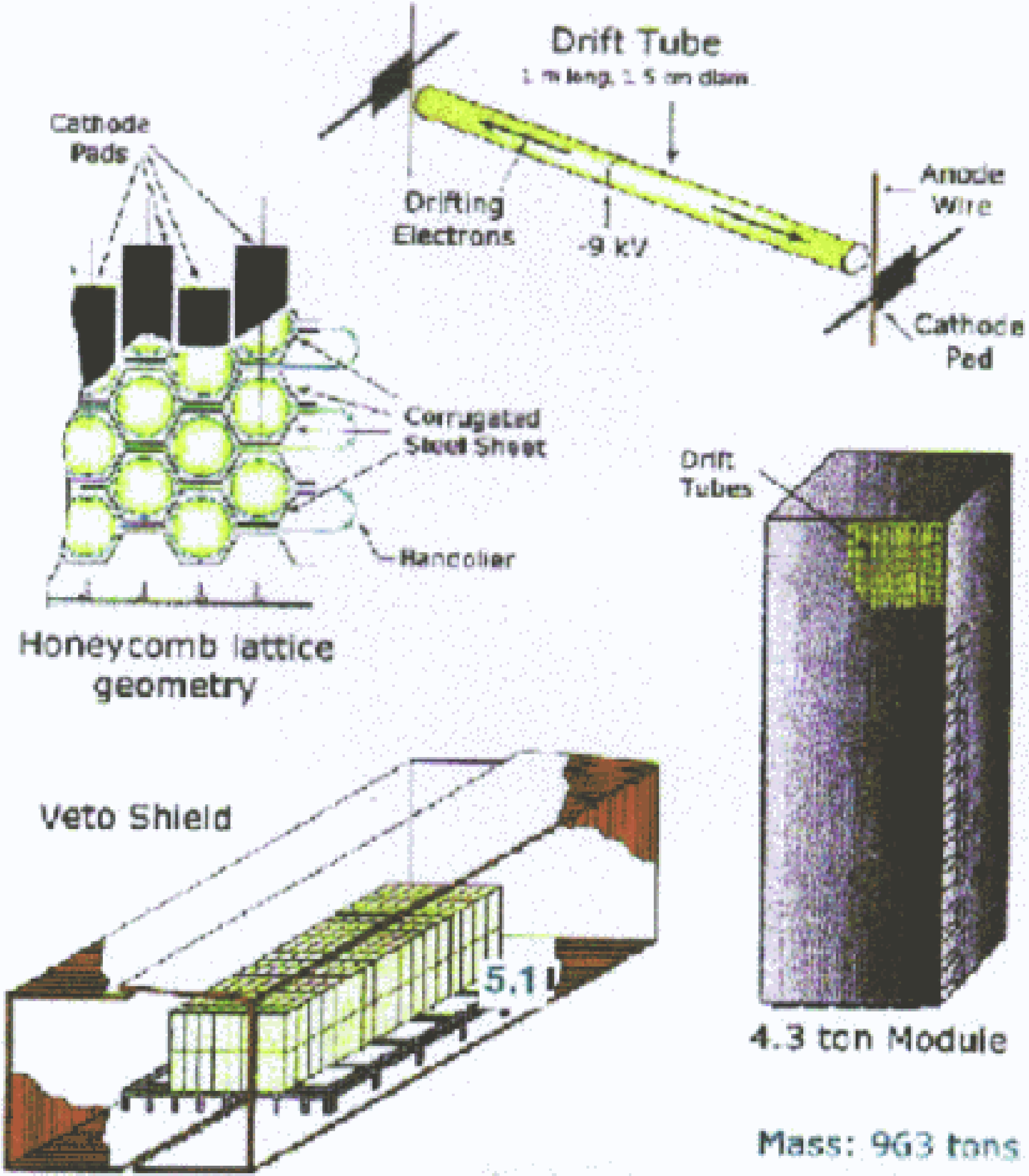
-Monolith

SOUDAN2

-The Soudan2 Detector is a fine-grained iron tracking calorimeter(since April 89)
in the Soudan Mine Underground State Park-Minnesota).
-Basic detector : slow-drift time projection chamber.
-Assembly of tubes : with mylar sheets interlived with corrugated steel sheets (honeycomb geometry):1 Mod.=4.3 tons;
224 Modules ≐ 1 Kton
-The calorimeter is surrounded by a double –layer of proportional tubes (Active Shield of 1700 m^2 , used as veto).
-Very good tracking ; very good separation of CC ν_μ / ν_e events.

The Soudan2 Detector

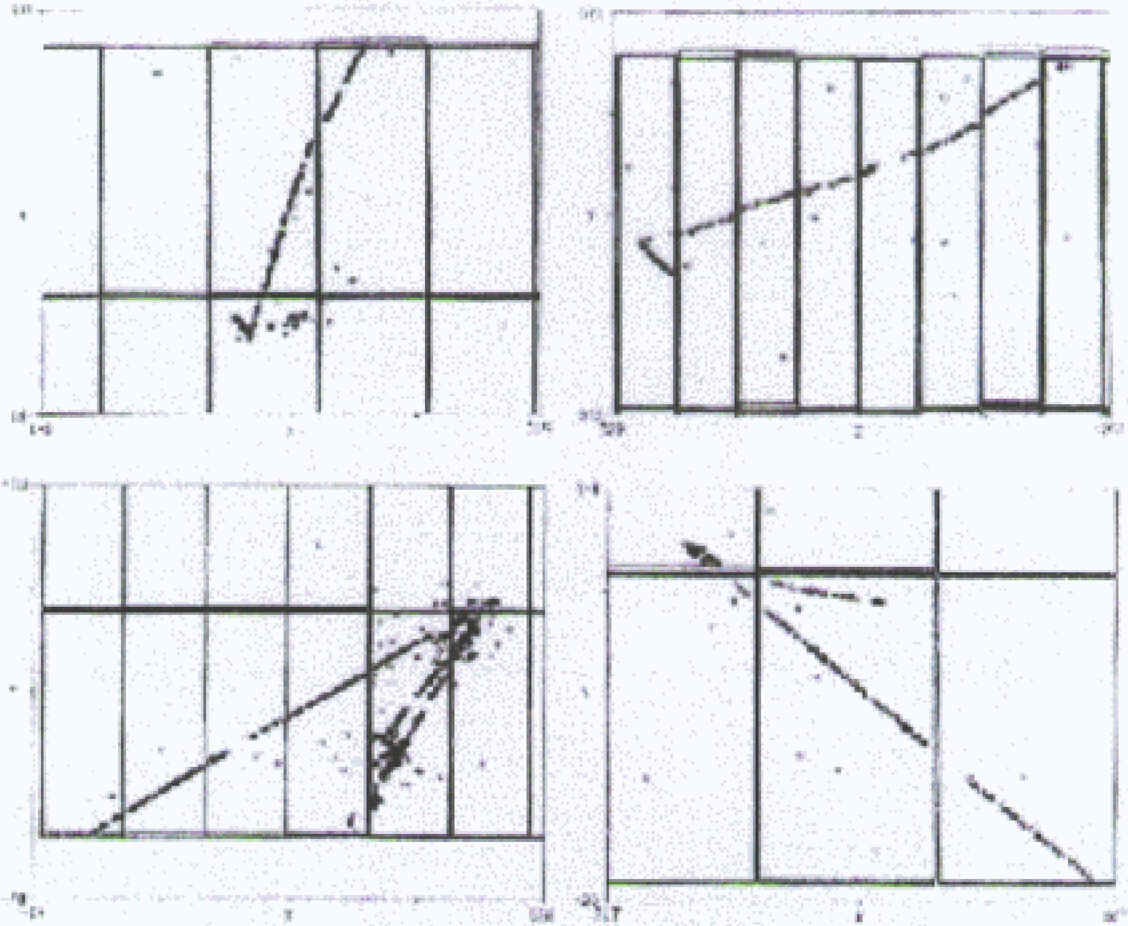
Slow-drift time projection chamber



Mass: 963 tons

Analyzed exposure: 5.1 fid. kty

Partially contained events



Select events with non-scattering, exiting track;

ν_μ - flavor assignment is reliable (> 98%).

ν_μ PCEs are energetic and "point" well:

$\langle E_{vis} \rangle_{PCE}$ = 4.7 GeV (vs 1.3 GeV for ν_μ HiRes)

$\langle$Angle ν_μ vs recon.$\rangle_{PCE}$ = 14°.

-Background : from inelastic interactions of cosmic ray μ's with nuclei of the rock

-" Gold Tracks " events ($\simeq \nu_\mu$)

" Gold Showers " events ($\simeq \nu_e$)

RESULTS

- ν Flavor Ratio:

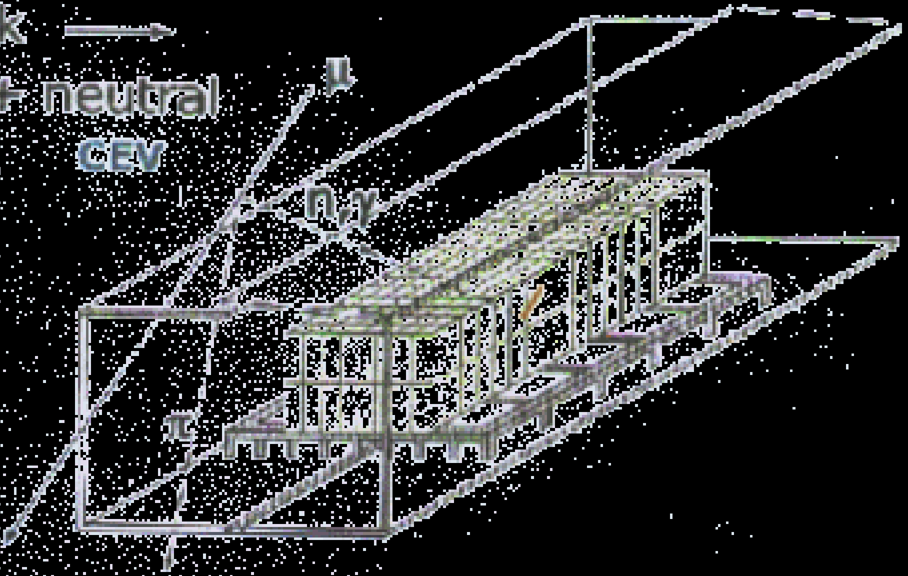
  $R=0.68 \pm 0.11 \pm 0.06$
- Angular Distributions
- L/E distributions (comparison with no osc. M.C. and with OSC. With different values of the parameters Δm^2 and $\sin^2(2\theta)$
- Confidence Level Regions

Non-neutrino cosmic-ray background:

μ + Rock ⟶

μ + charged + neutral

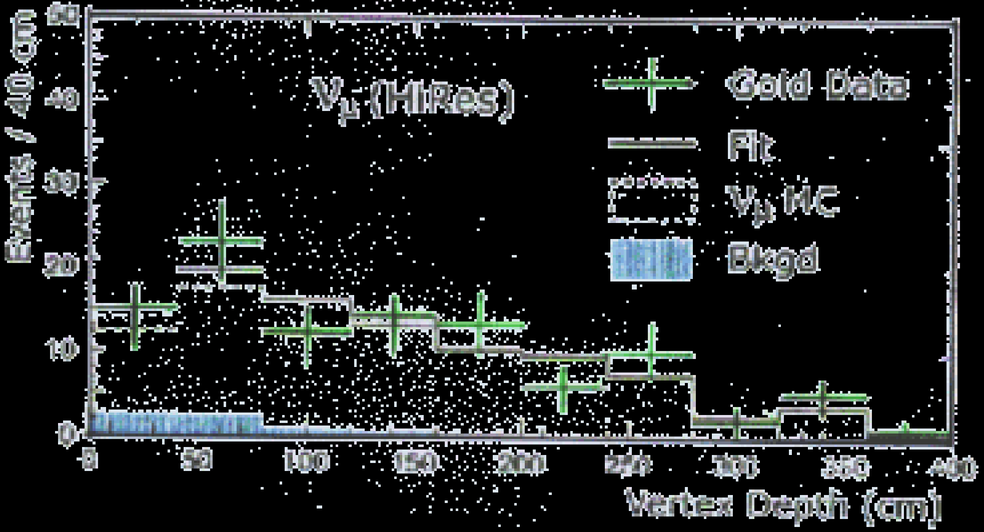
shield hits **CEV**



"Rock event" sample-

Identified by presence of shield hits.

The residual zero-shield-hit background is calculated by fitting contained event vertex-depth distributions to a combination of Rock and ν Monte Carlo distributions:



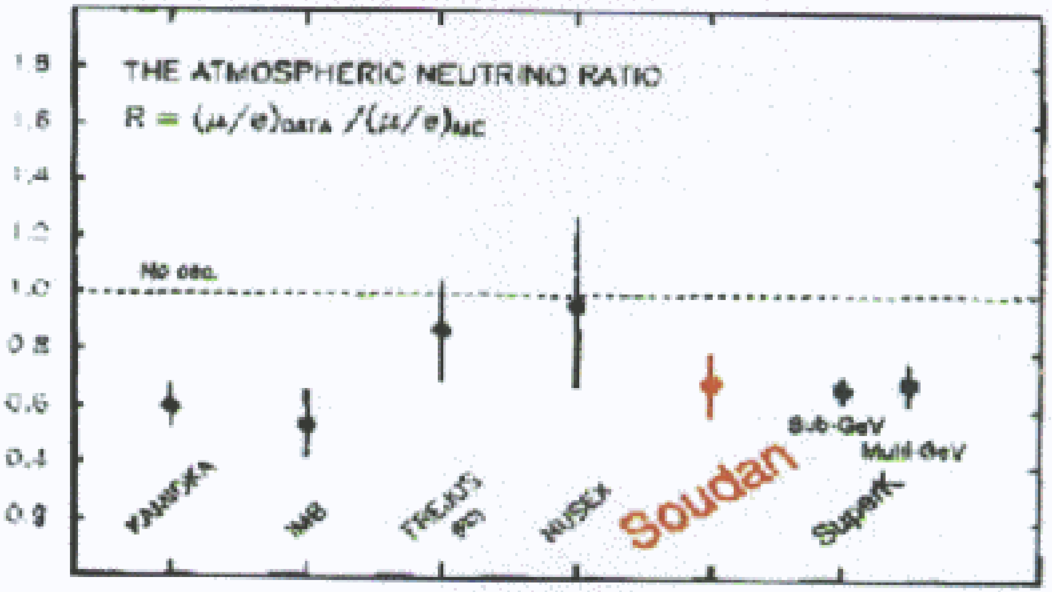
SOUDAN 2
R Measurement

- 5.1 kton year of data (still statistics limited)
- Gold Events without the veto shield. Residual background estimated via vertex depth distribution

Gold Tracks (133)- Background	**105.1±12.7**
Gold Showers(193)-Background	**142.3±13.9**
MC Tracks (scan 1097)	**193.1 (Bartol 96 ν flux)**
MC showers (scan 1017)	**179**

$$R\left(\frac{\mu}{e}\right) = R\left(\frac{\dfrac{tracks}{showers_{data}}}{\dfrac{tracks}{showers_{MC}}}\right) = 0.68 \pm 0.11 \pm 0.06$$

(same value as in 1999)



SOUDAN 2 - L/E measurement

- in the two neutrino scenario the physical quantity is L/E; to increase the resolution in L/E selection of :

High resolution sample:

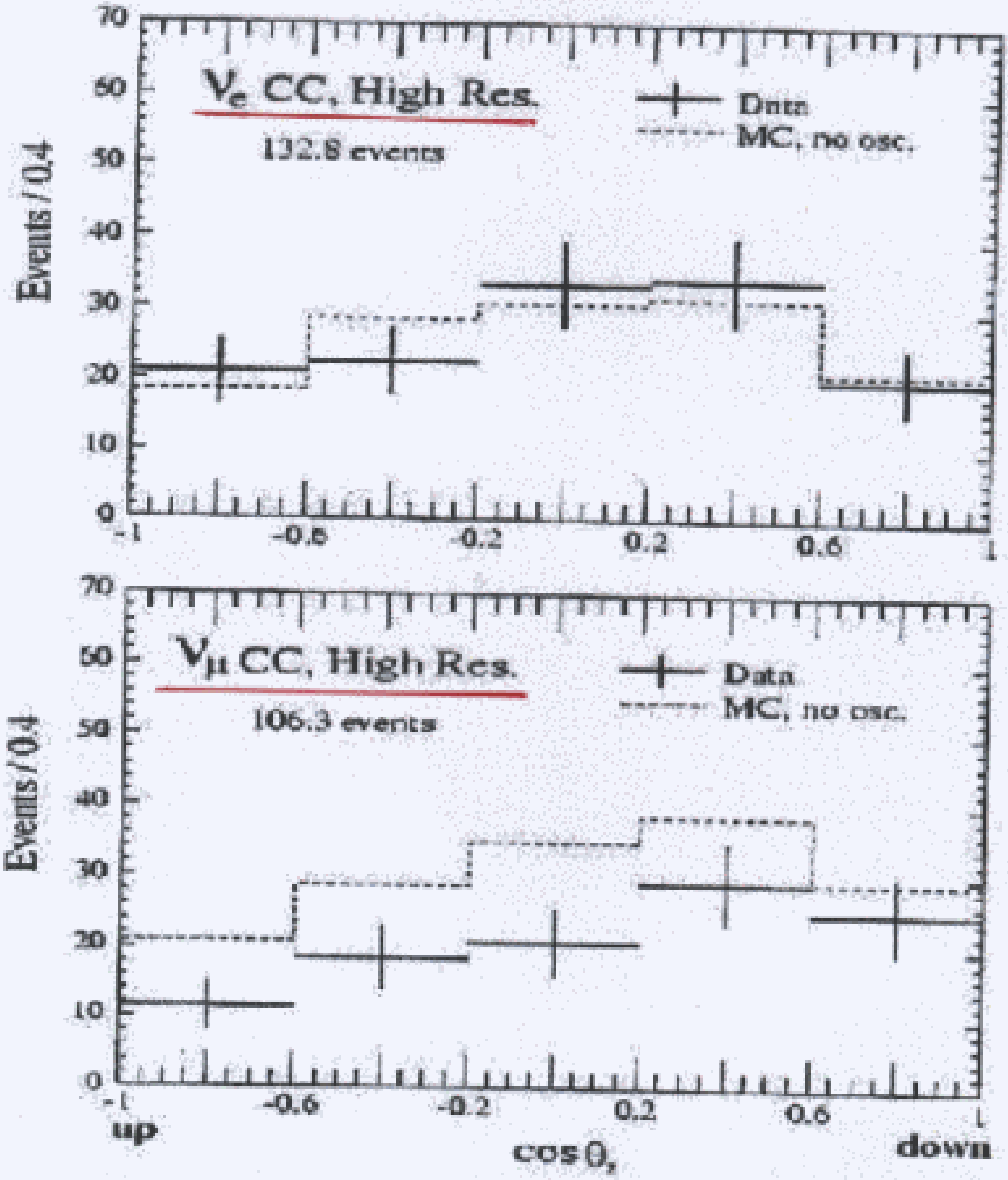
1) Quasi-elastic (Tracks, Showers)
   Plepton> 150 Mev/c
   or
   Evis > 600 MeV/c if a recoil is measured
2) Multiprongs
   Evis>700 MeV/c
   Plepton>250 MeV/c (to improve flavor) tag
   $\sum |P_{vis}| > 450 MeV / c$

Resolutions

	νμ CC	νe CC
Energy (ΔE/E)	**20 %**	**23%**
Angle	**33.2°**	**21.3°**
Log(L/E)	**0.49**	**0.43**

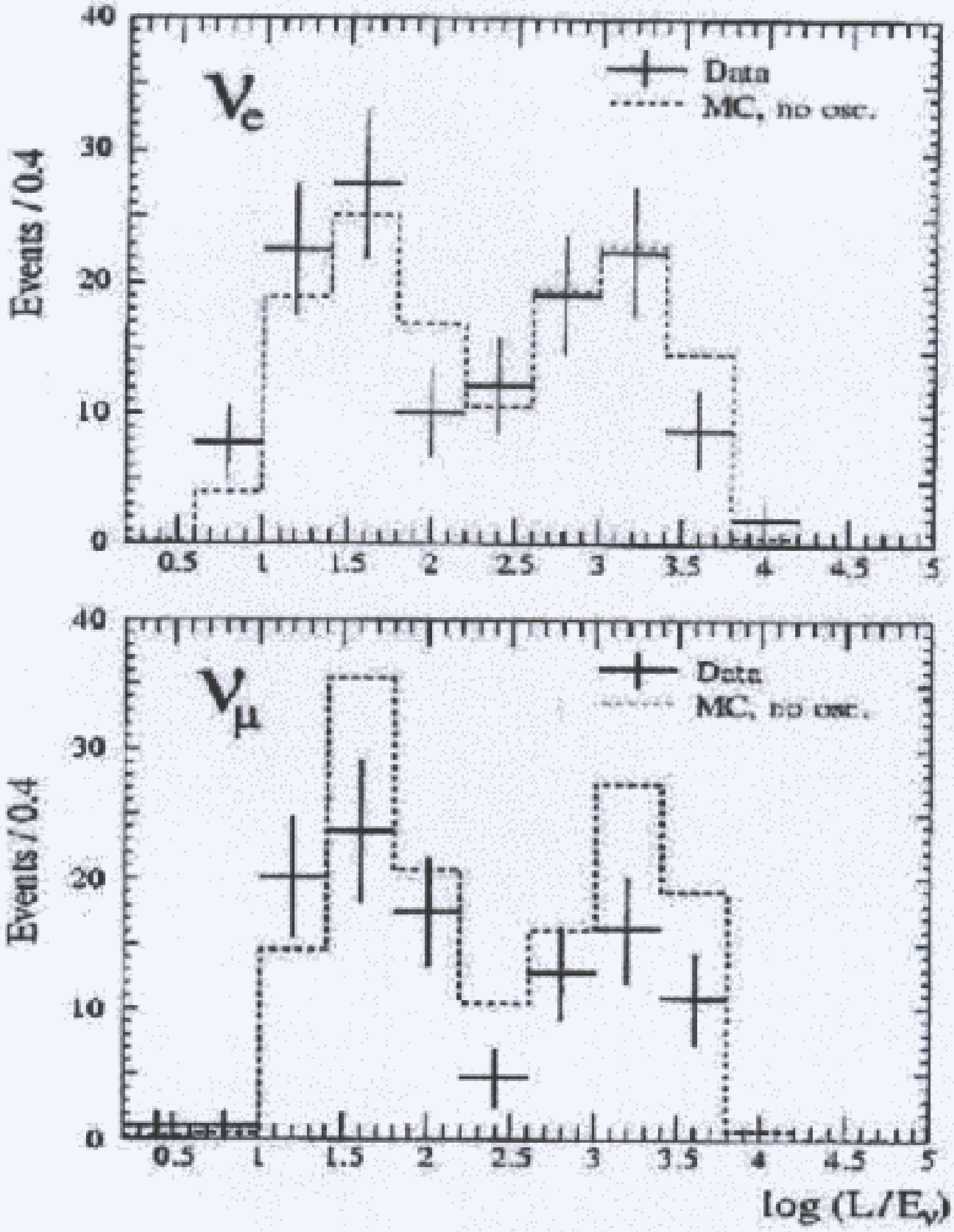
	νμ	νe
Events(bck subtracted)	106.3±14.7	132.8 ±13.4
MC (Bartol)	200.6	168.1

SOUDAN 2 - Angular Distributions

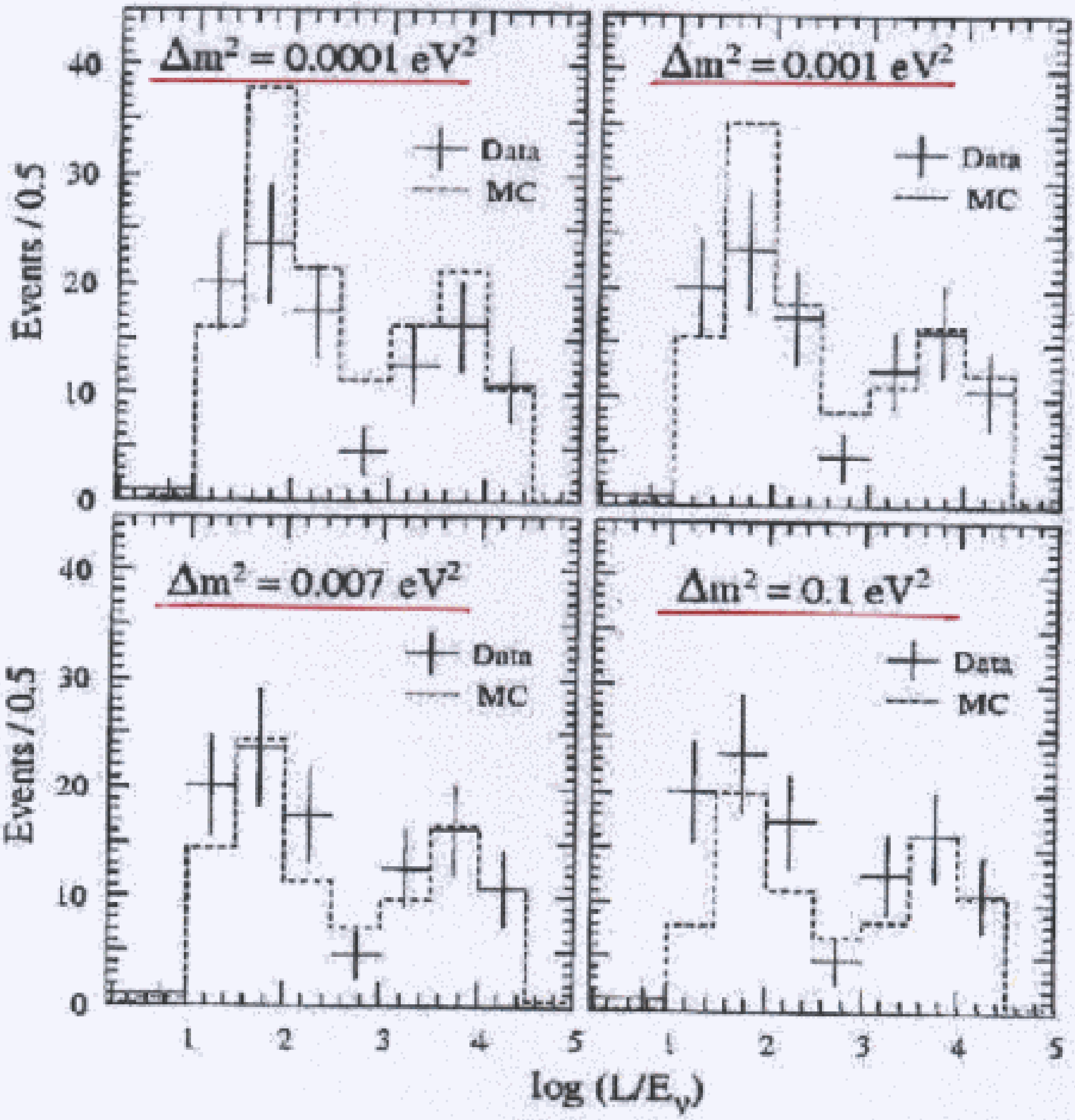


- in the plots normalization factor from νe
- Up-Down Asymmetry in MC(geomagnetic field)

SOUDAN 2 - L/E Distributions

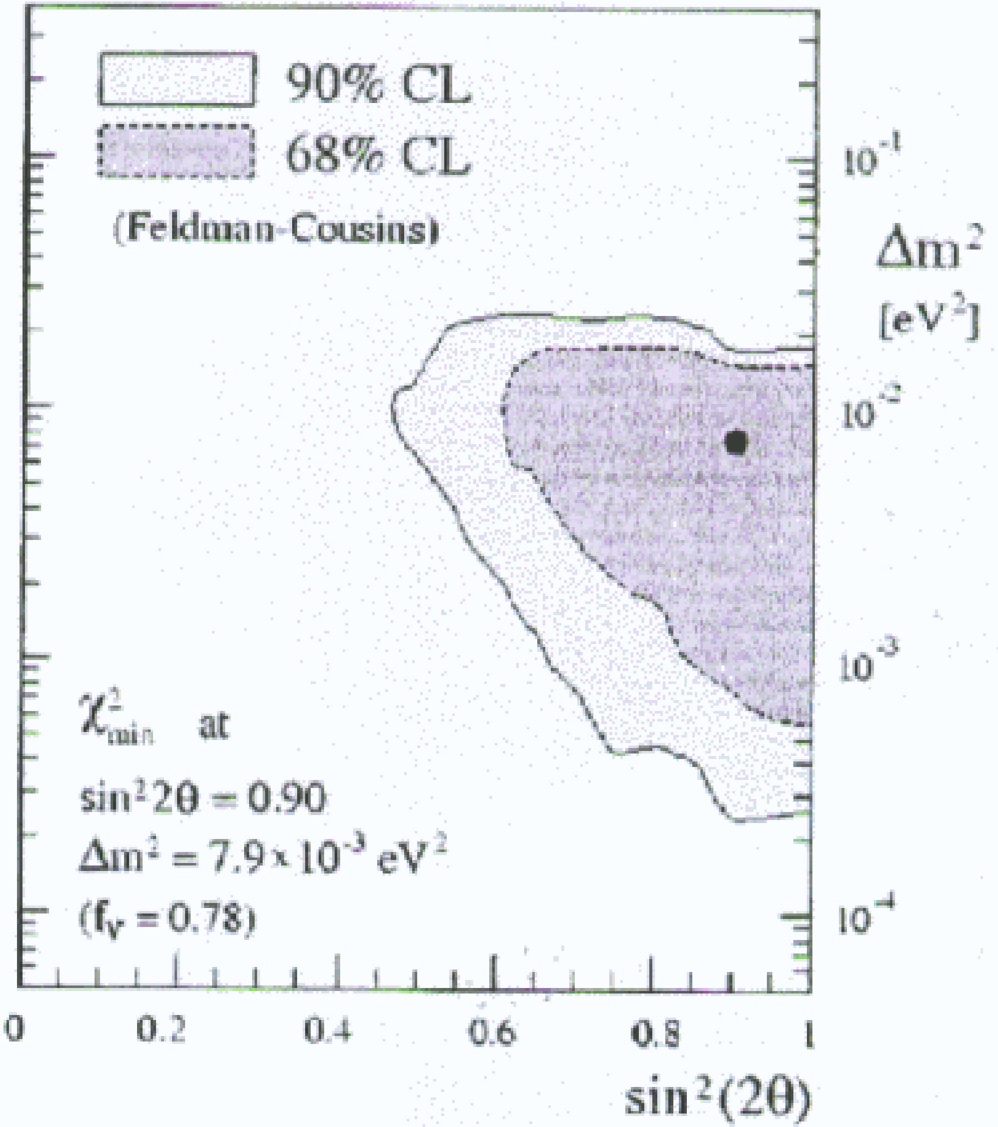


SOUDAN 2 - L/E Distributions (maximum mixing)



Distortion of the L/E distribution respect the no-oscillation Montecarlo

SOUDAN 2
Confidence Level Regions
(Feldman Cousins)



MACRO

- Characteristic Feature of MACRO

ν's Events Topologies :

a)Up throughgoing μ's (ToF)

b)Internal Upgoing μ's (ToF)

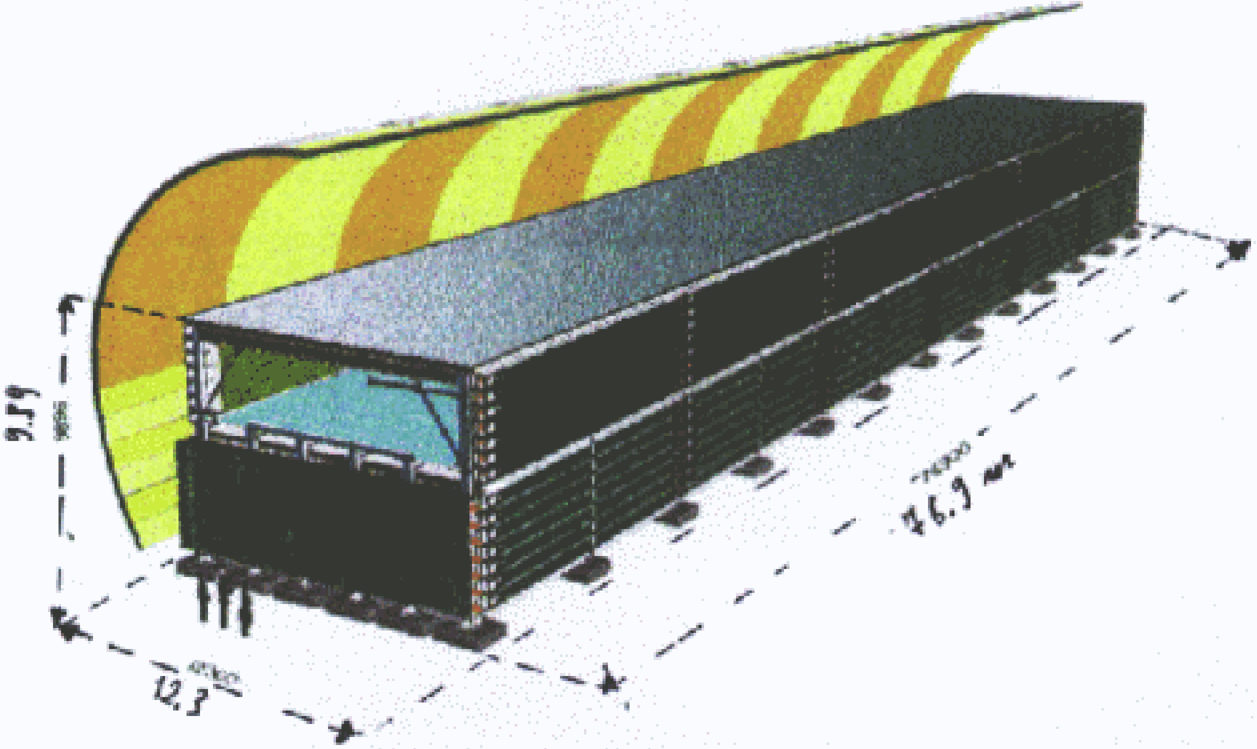
c)Internal Downgoing (No ToF)
and
Upgoing stopping μ's (No ToF)

- Energy Distribution of the 3 categories

UPGOING μ's

- The Selection of the upgoing μ's is obtained by ToF measurements
- The ratio:
  R=data/prediction $=0.73\pm0.028\pm0.04\pm0.12$
- Angular Distributions : a)No Osc. $P=0.9\%$
  b)Osc. $P=26\%$
  $(\nu_\mu\ \nu_\tau\ (\Delta m^2= 2.5\ 10^{-3}\ \mathrm{eV}^2\ ;\sin^2(2.\theta)=1)$

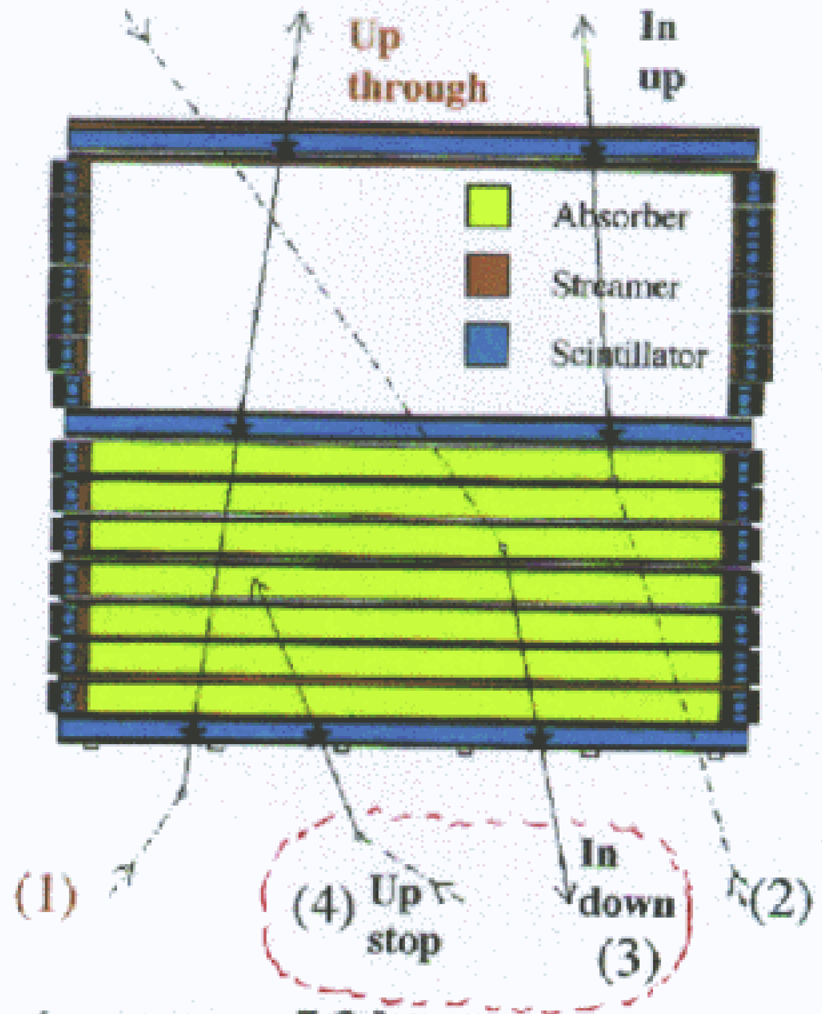
Main features of Macro as ν detector



- **Large acceptance** (~10000 m^2sr 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 ~500psec)
- **~20000 m^2 of streamer tubes (3cm cells) for tracking** (angular resolution < 1°)

More details in Nucl. Inst. and Meth. A324 (1993) 337.

Neutrino event topologies in MACRO



Detector mass ~ 5.3 kton

(1) Up throughgoing μ (ToF) ~140 Ev/y

$E_{median} \approx 50$GeV

(2) Internal Upgoing μ (ToF) ~ 25/y $E_{median} \approx 3.5$GeV

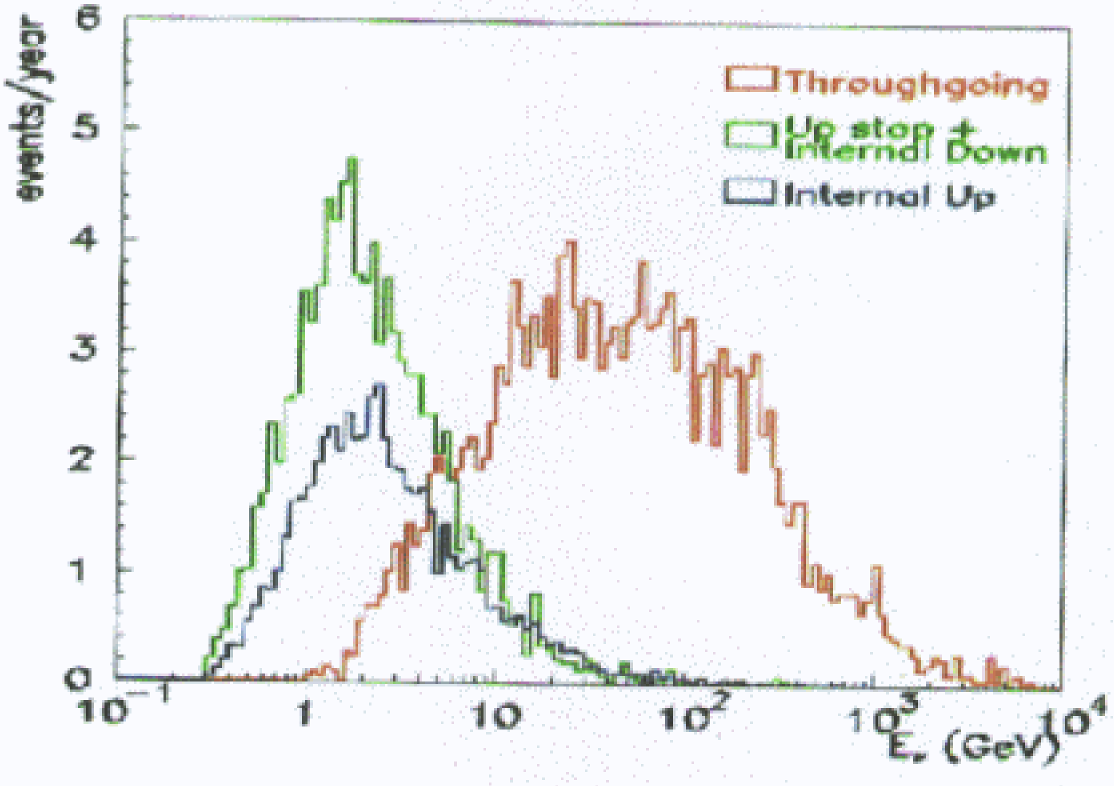
(3)

(3) Internal Downgoing μ (no ToF) ~ 22y

$E_{median} \approx 4.2$GeV

(4) UpGoing Stopping μ (no ToF) ~ 22/y

Energy spectra of ν events
detected in MACRO



$E_{median} \approx 50$GeV for Throughgoing muons;
$E_{median} \approx 3.5$GeV for Internal Upgoing (IU) μ
$E_{median} \approx 4.2$GeV for Internal Downgoing (ID) μ
and for UpGoing Stopping (UGS) μ;

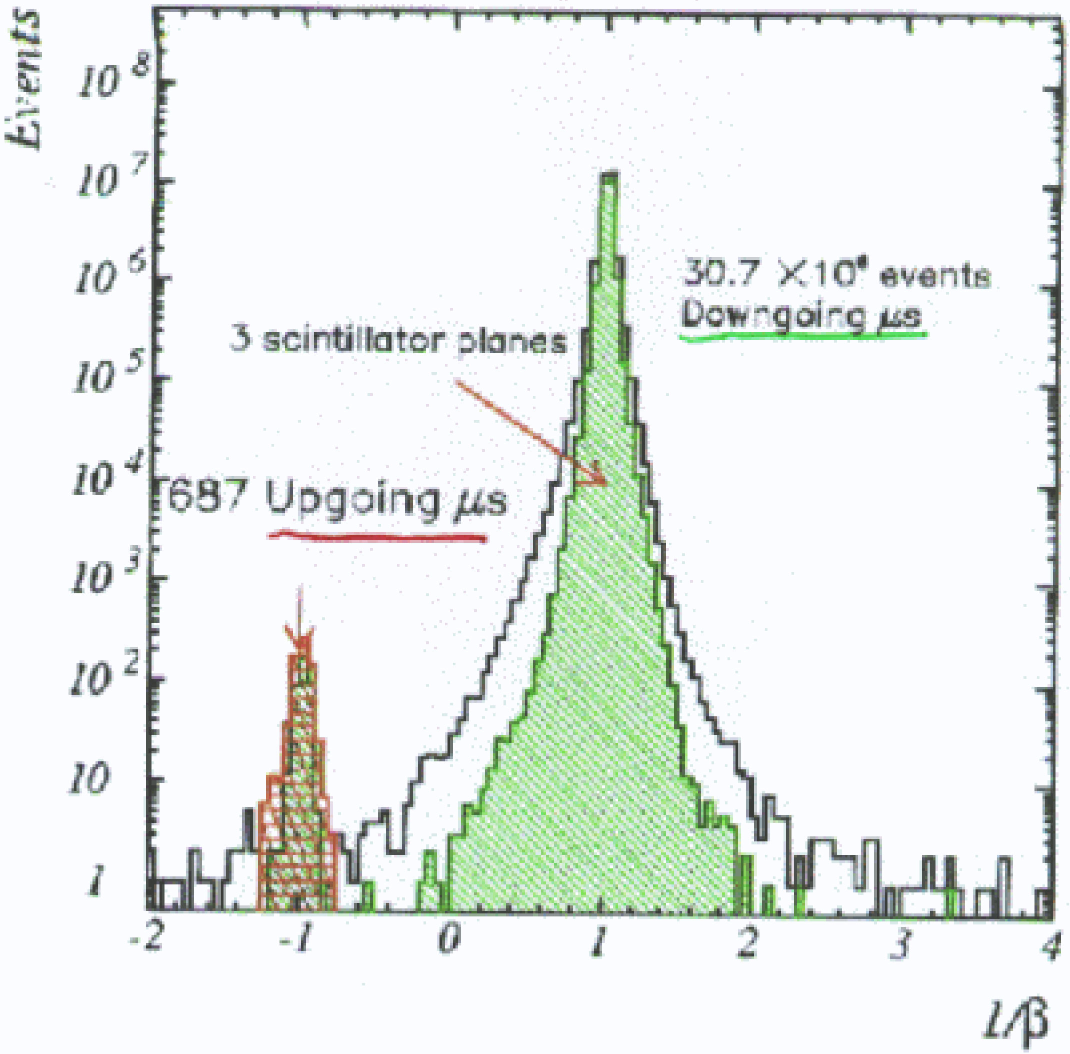
Low energy events (IU, ID+UGS) allow to investigate the oscillation parameter space independently from throughgoing muons

Upward Going Muons (Through) Results

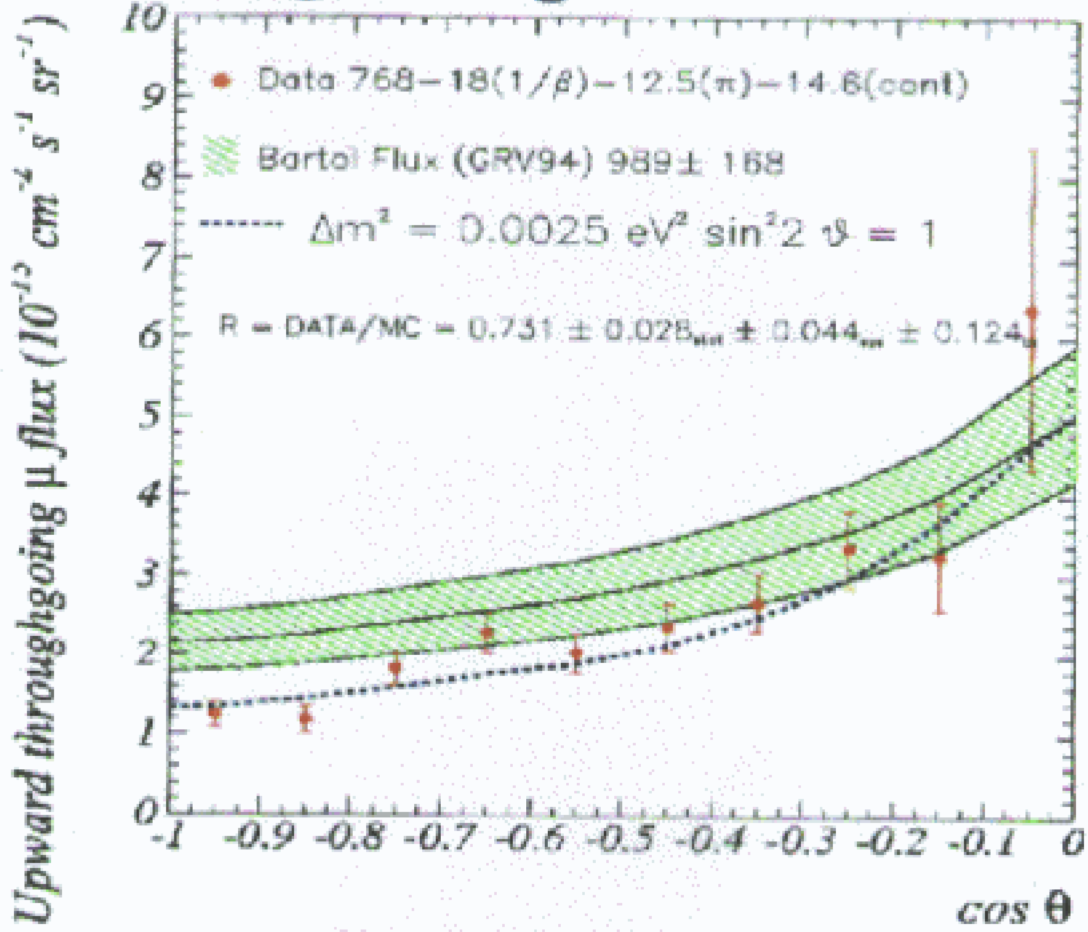
Total number of events:	**768**
background (wrong b)	18
background (pion from muon)	12.5
Internal neutrino interactions	14.6
Total	**723**
Prediction	**989±17%**
Bartol neutrino Flux ±14%	
GRV94 cross section 9%	
Lohmann muon energy loss 5%	
R=data/prediction=	**0.73**

±0.028(stat)±0.044(systemat.)±0.12(theoretical)

Upward Going Muons
1/β distribution



Upward Going Muons (Through) Angular Distribution



χ^2 test on the angular distribution (10 bins) with prediction normalized to data :

- **$\chi^2 = 11.2/9$ d.o.f.** $\boxed{\text{for } \nu_\mu \Rightarrow \nu_\tau}$ with maximum mixing and $\Delta m^2 \sim 0.0025\ eV^2$ P = 26 %
- **$\chi^2 = 24.3/9$ d.o.f.** for no - oscillations P = 0.9 %

(since <Eμ thresh>≈ 1 GeV MACRO should be compared with the SuperKamiokande Through-going + Stopping muons)

- Separation of the two hypothesis I) $\nu_\mu \to \nu_\tau$
  II) $\nu_\mu \to \nu_s$

-From the number of events and from the angular distribution : $\nu_\mu \to \nu_\tau$ favored : 57% Prob.
: $\nu_\mu \to \nu_s$: 14.5% Prob.

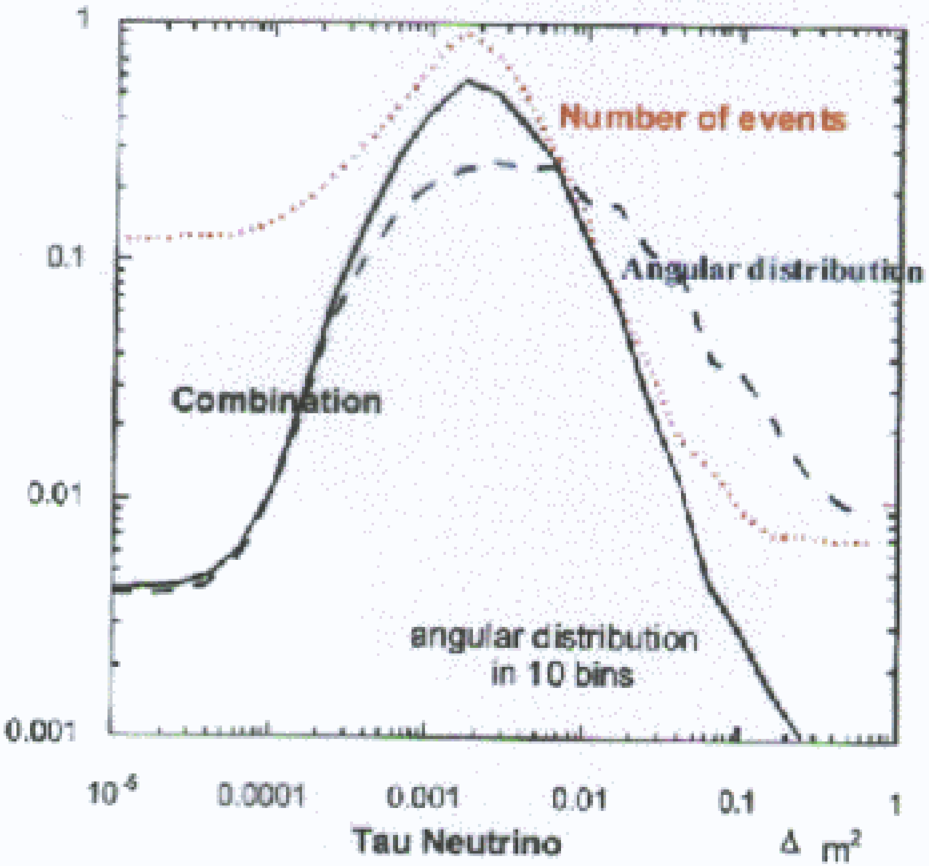
-From the ratio VERTICAL/HORIZONTAL

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

(more sensitive)

ν_s disfavored respect ν_τ
at > 98% for any mixing

Probabilities for maximum mixing and ν_{μ}--> ν_{τ} oscillations

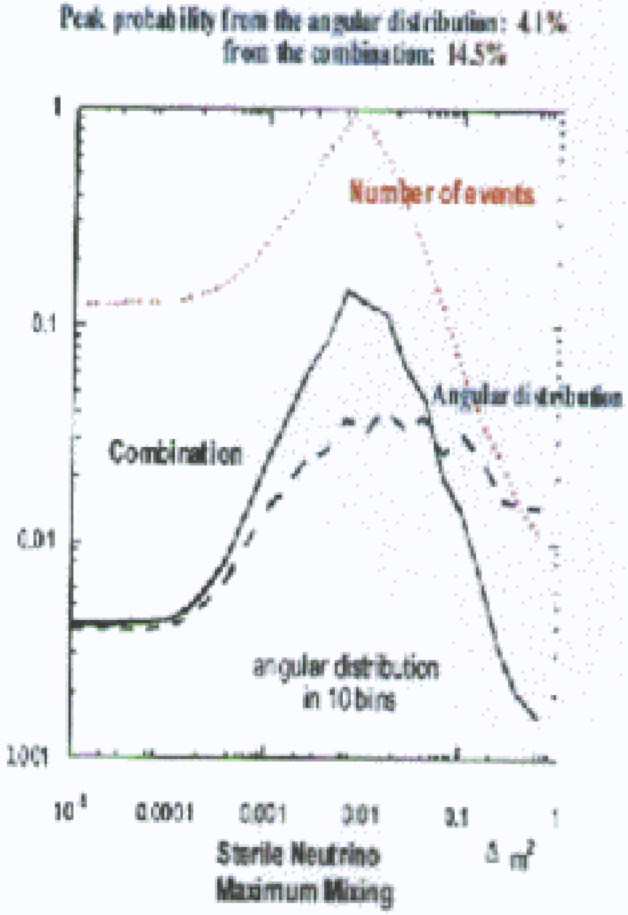


Peak probability from the angular distribution: 26%
from the combination: 57%

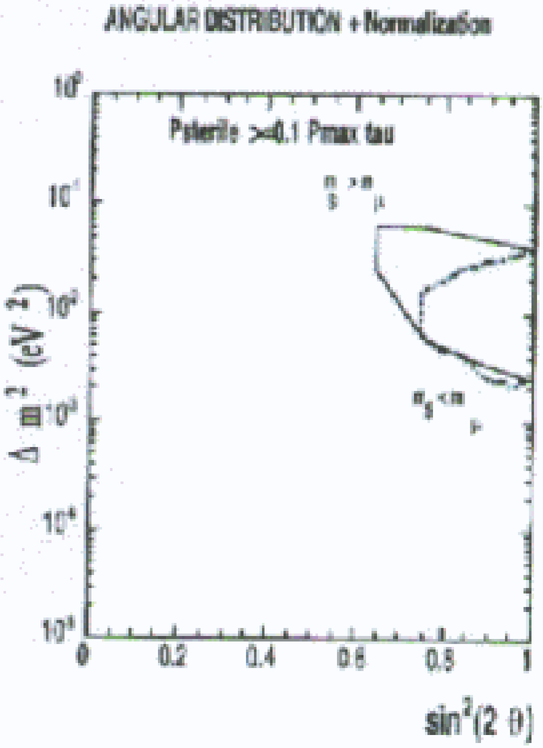
- The peak probability from the angular distribution alone is in the same region of the peak probability from the total number of events
- Probability for no-oscillation: ~ 0.4 %

MACRO UPMU
Probability for sterile neutrinos oscillations

- sterile neutrino ==>> matter effects ==> reduction of the angular distortion



Peak probability from the angular distribution: 4.1%
from the combination: 14.5%



ANGULAR DISTRIBUTION + Normalization

Peak probabilities lower than that for tau neutrinos: ↘

- **from the angular distribution:** 4.1 % 26 %
- **from combination:** 14.5 % 57 %

MACRO UPMU : matter effect with the ratio vertical/horizontal

- This ratio (*Lipari -Lusignoli (Ph Rev D 57 1998)*) can be statistically more powerful than a chi-square test for two reasons:

  1) the ratio is sensitive to the sign of the deviation

  2) there is gain in statistical significance grouping data in two bins

- As disadvantage you could lost some data structure in the angular distribution

- Ratio or chi-square in 10 bins ? Several authors prefer chi-square.

Chi-square in 10 (or more) bins **no strong discrimination between tau and sterile neutrino** oscillations (for SK also)

(Foot hep-ph/0007065 , Fornengo et al hep-ph/0002147)

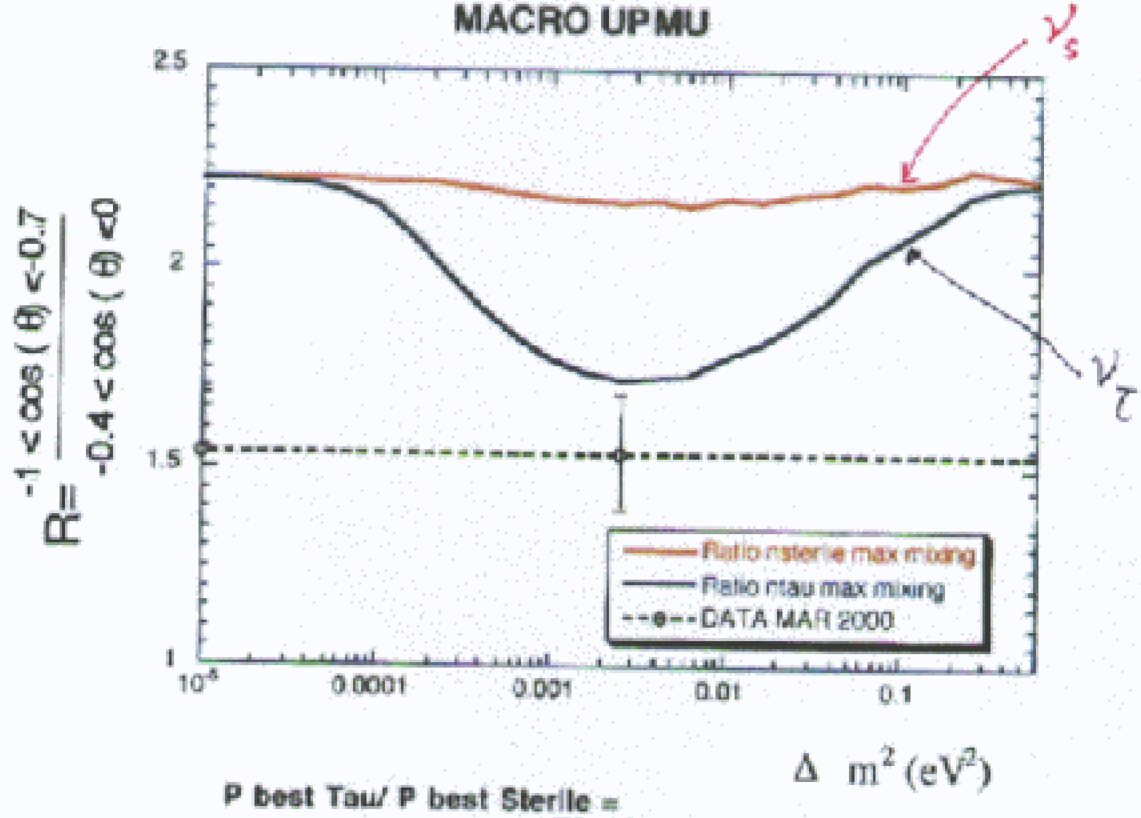
- **Recently : optimization of the ratio**

Result (for MACRO) for the best bin combination

$$R = \frac{N(\cos(\theta) < -0.7)}{N(\cos(\theta) > -0.4)}$$

Obtained from a Montecarlo simulation to minimize the probability for sterile neutrino assuming tau neutrino oscillations with $\Delta m^2 = 0.0025\ eV^2$

Ratio vertical/horizontal Montecarlo Optimized



P best Tau/ P best Sterile =
70 (5% systematic in each bin)
413 (no systematic error)

- **The plot is for** Maximum mixing.
- **Sterile neutrino disfavored respect to tau at >98% for any mixing** (5% systematic in each bin)

INTERNAL UPGOING

- $R = (\mathrm{Data/MC})_{IU} = 0.55 \pm 0.04 \pm 0.06 \pm 0.14$

INTERNAL DOWNGOING +UPGOING
μ STOPPING

- $R = (\mathrm{Data})/\mathrm{MC})_{ID+UGS} = 0.70 \pm 0.04 \pm 0.07 \pm 0.18$

UP-DOWN ASYMMETRY

- $R_{DATA} = \mathrm{IU}/(\mathrm{ID}+\mathrm{UPS}) = 0.59 \pm 0.07(\mathrm{Stat.})$

$R_{NO\ OSC.} = 0.75 + 0.04(\mathrm{Syst.}) \pm 0.04(\mathrm{Theor.})$

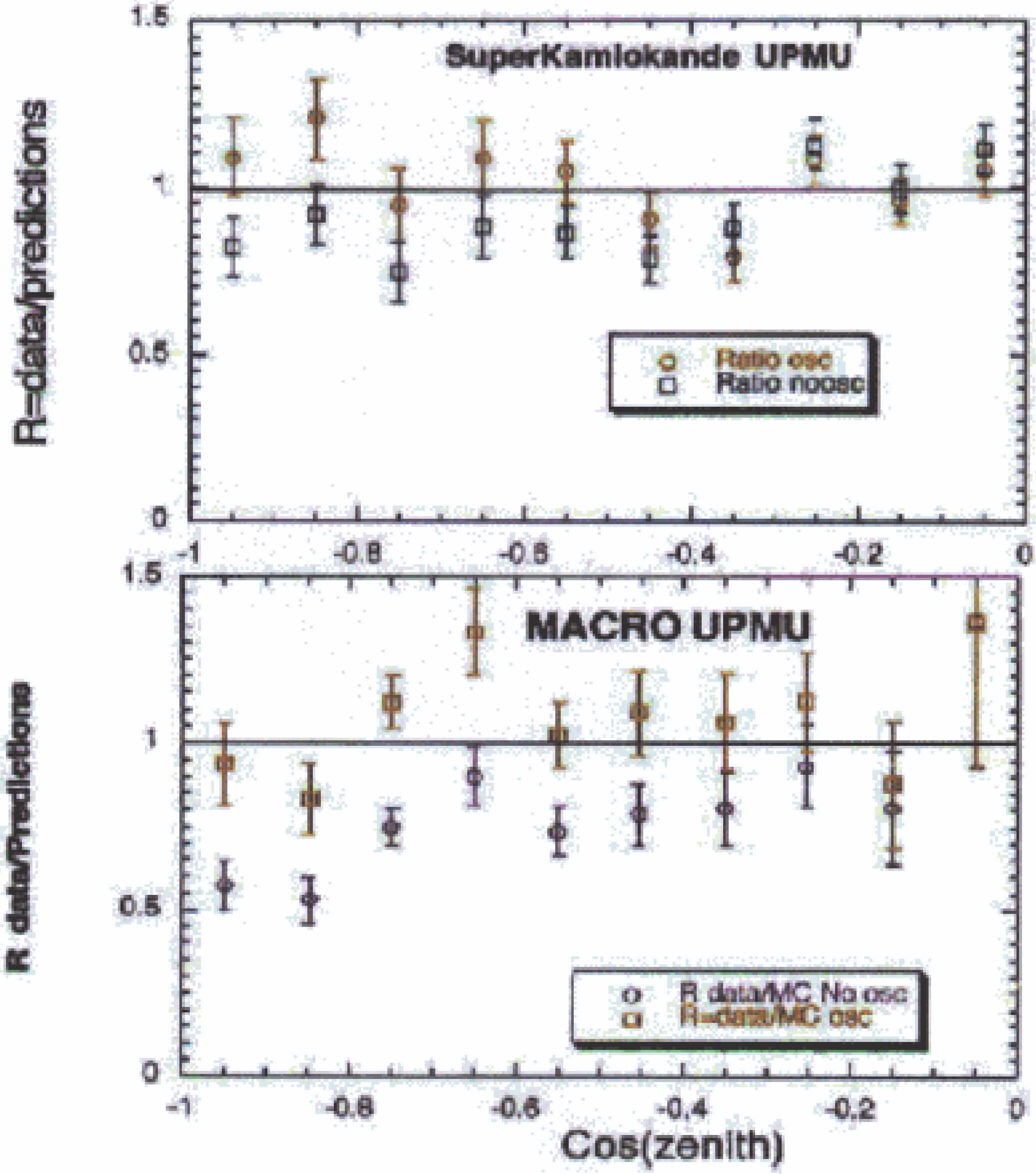
$R_{(\Delta m^2 = 2.5\ 10^{-3}\ eV^2 ; \sin^2 2\theta = 1)} = 0.58 \pm 0.03 \pm 0.03$

(Compatibility $R_{DATA} - R_{NO\ OSC}$: 2.7 %)

- General Results From MACRO

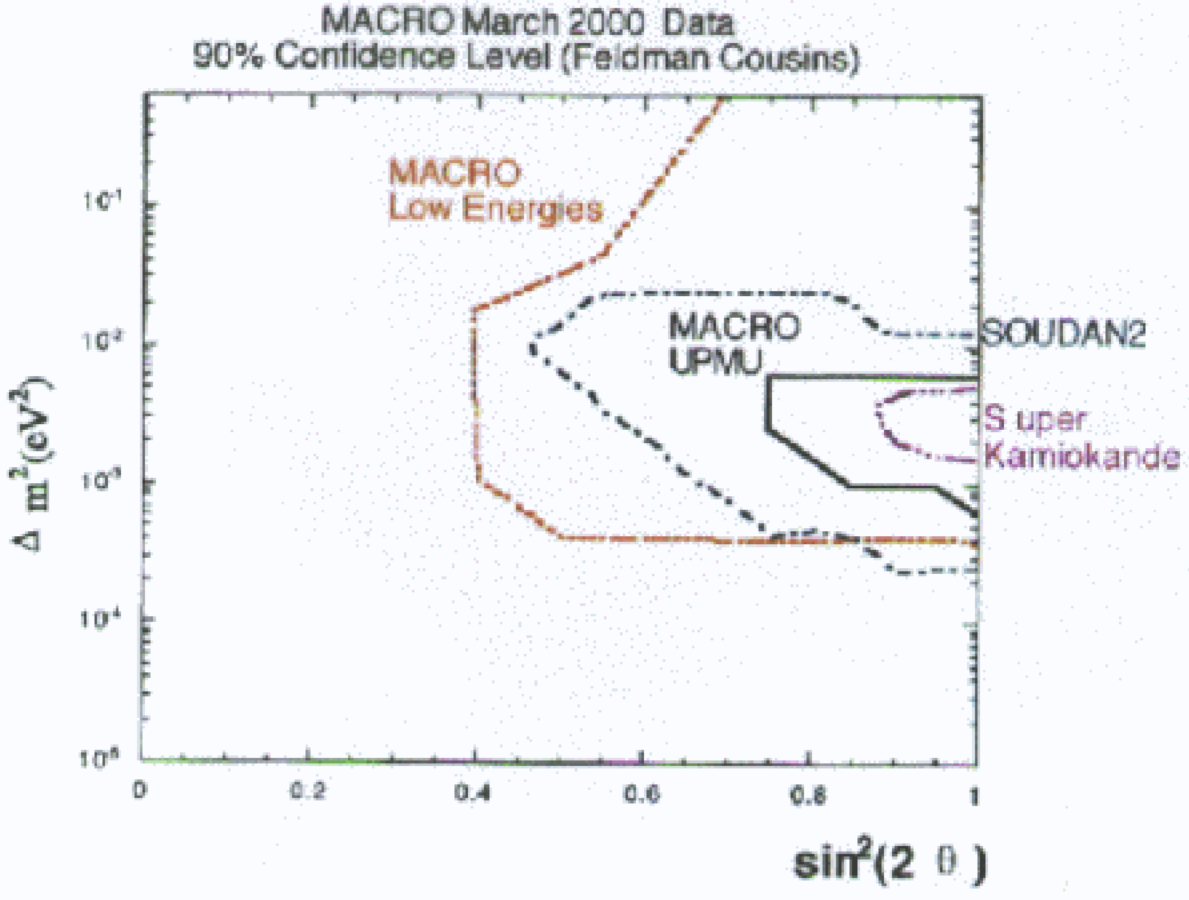
Ratio data/predictions

(UPMU)



Confidence level regions

(ν_μ--> ν_τ oscillations)



FUTURE

- Why atmospheric ν's ?

-Large L/E range

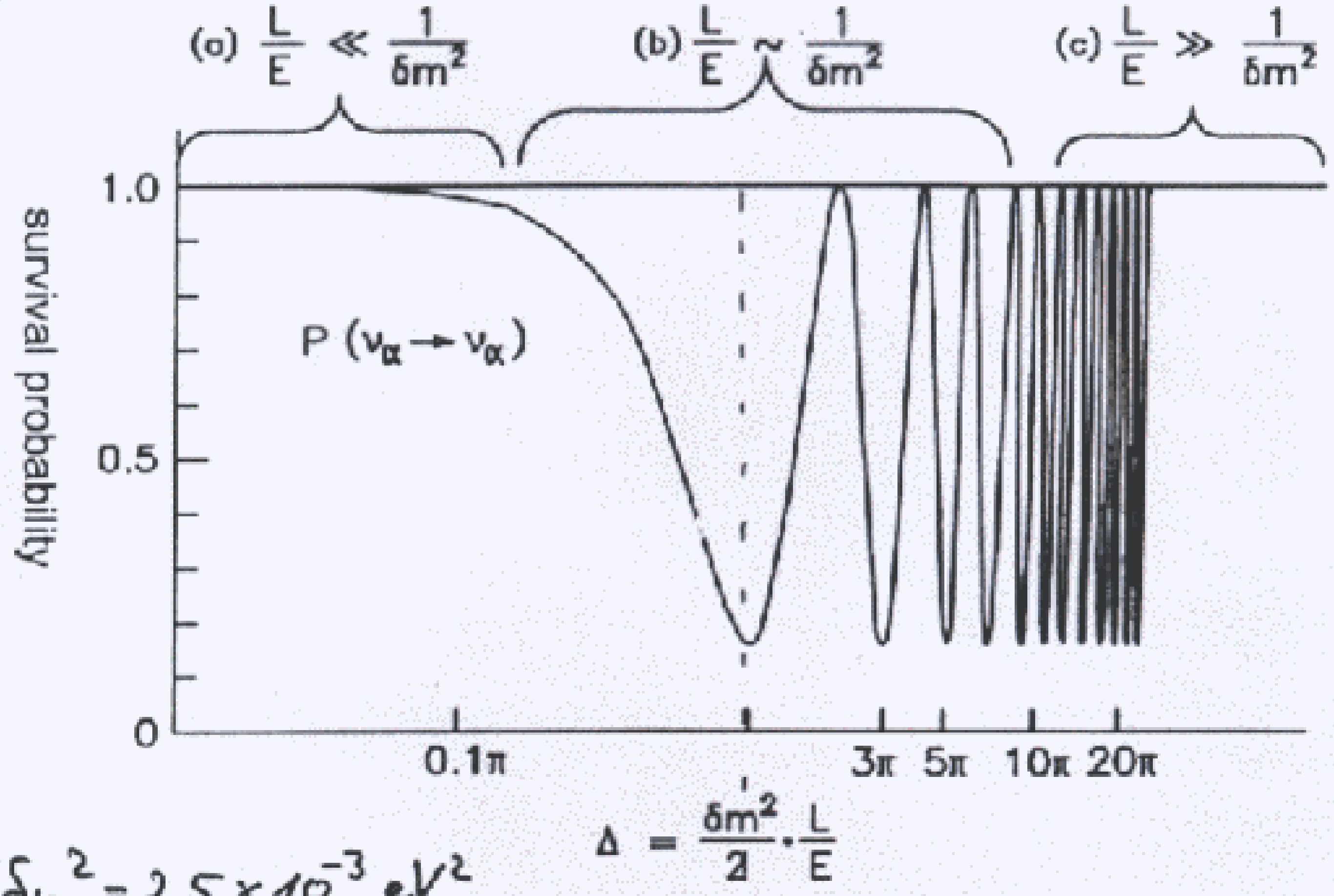
-Tho different sources and the same Detector

-L up to 13.000 Km (Matter effects)

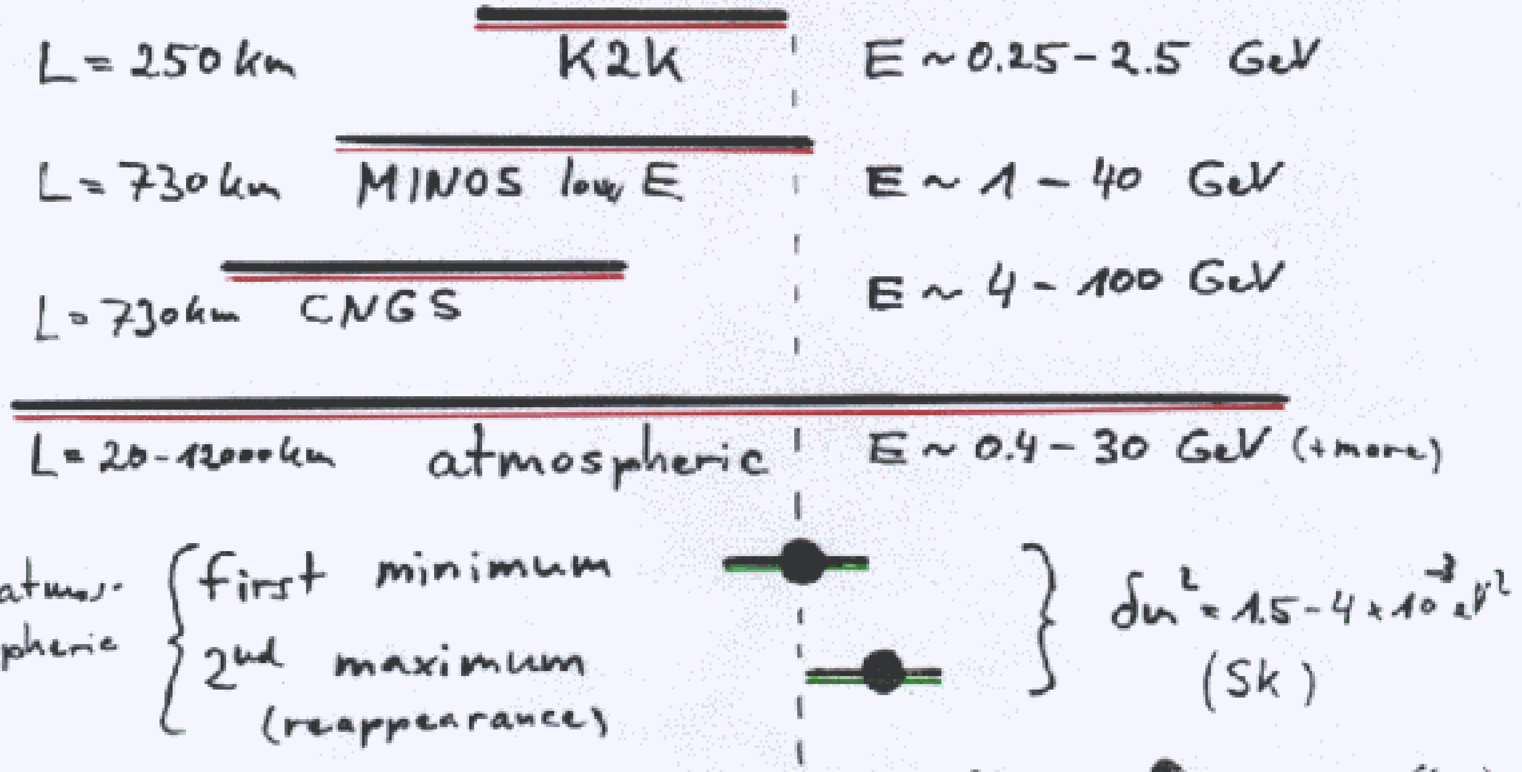
- With suitable Detectors , possibility to observe the oscillation pattern with discrimination between the oscillation hypothesis and others (Decay etc.)

- If Oscillations will be proved , possibility to determine combinations of (ν_μ to ν_τ) and (ν_μ to ν_s)

L/E range



$\delta m^2 = 2.5 \times 10^{-3}\ eV^2$



L = 250 km K2K E ~ 0.25 – 2.5 GeV

L = 730 km MINOS low E E ~ 1 – 40 GeV

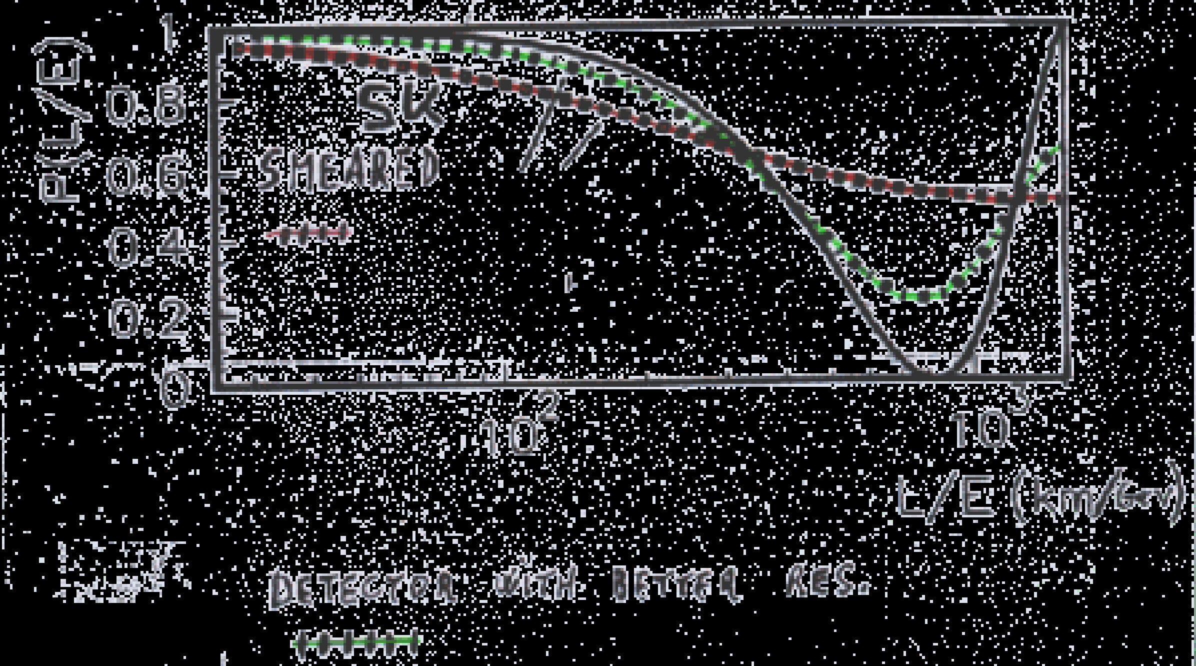
L = 730 km CNGS E ~ 4 – 100 GeV

L = 20 – 12000 km atmospheric E ~ 0.4 – 30 GeV (+more)

atmospheric { first minimum / 2nd maximum (reappearance) } $\delta m^2 = 1.5 - 4 \times 10^{-3}\ eV^2$ (SK)

(solar $\delta m^2 \sim 1 \times 10^{-4}\ eV^2$)

oscillations smeared
by detector resolution



- The detectors must have :

  -Large Mass (see S.K.)

  - Very good L/E resolution

-Two Kinds of detector proposed :

a) With Mass $M \gg M_{S.K.}$

b) With Mass $M \simeq M_{S.K.}$
but with better resolution in L/E

Class a) Megaton water Cerenkov

Class b) Multi Ktons liquid Argon (Super
Icarus)
Nice
Monolith
ETC. ....

MONOLITH

- THE DETECTOR

-LARGE MASS $\simeq$ 35 KTONS

-MAGNETISED FE SPECTROMETER B= 1,3TESLA

-SANDWICH OF FE SLABS/GLASS SPARK COUNTERS

- 52.000 M^2 OF SENSITIVE DETECTOR

-PROPOSED FOR THE GRAN SASSO LABORATORY

PHYSICS GOALS

-Prove ν' s Oscillations through the observation of the oscillation pattern

-Improve the measurement of the parameters Δm^2 and $\sin^2 2\,\theta$ (if oscillations)

-Test the admixture of ν_s and ν_e searching for matter induced effects

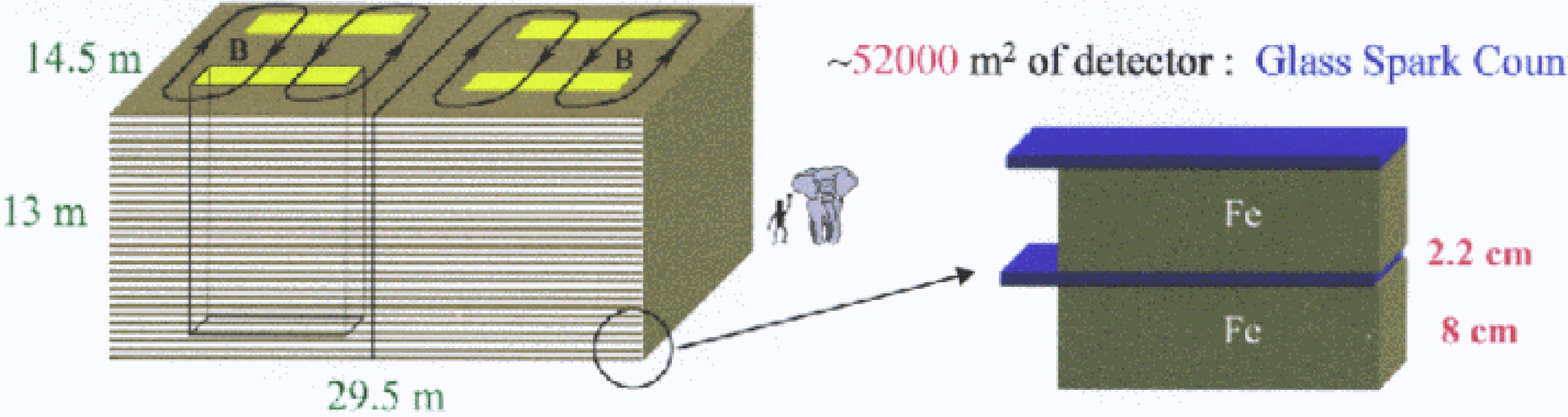
Institutions

[1] Institute for Nuclear Research (INR), Moscow, Russia
[2] INFN, Sezione di Napoli, Napoli, Italy
[3] Moscow Engineering Physics Insitute, Moscow, Russia
[4] Bologna University and INFN, Bologna, Italy
[5] Physics Department and Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027, USA
[6] Hamburg University, Hamburg, Germany
[7] Laboratoire de Physique Nucléaire et de Physique des Particules, Faculté des Sciences de Tunis, Tunis, Tunisia
[8] Laboratori Nazionali di Frascati and INFN, Frascati, Italy
[9] University of Torino, Torino, Italy
[10] INFN Sezione di Torino, Torino, Italy
[11] Dipartimento di Fisica, Università di Milano Bicocca and INFN, Milano, Italy
[12] Münster University, Münster, Germany
[13] Laboratori Nazionali di Gran Sasso and INFN, Assergi, Italy
[14] Istituto di Cosmogeofisica, CNR, Torino, Italy
[15] Bonn University, Bonn, Germany
[16] Physics Department University of L'Aquila and INFN, L'Aquila, Italy
[17] Physics Department in Frescati, Royal Institute of Technology, Stockholm, Sweden
[18] Rome University, Rome, Italy
[19] Humboldt University Berlin, Berlin, Germany

S. RAGAZZI (Spokesman)
(Mi)

The Monolith Detector

Large mass		34 kton
Magnetized Fe spectrometer		B = 1.3 Tesla
Time resolution		~ 1 ns (for up/down discrimination)
Space resolution		~ 1 cm (rms on X-Y coordinates)
Momentum resolution	σ_p/p	~ 20% from track curvature for outgoing mu
		~ 6% from range for stopping muons
Hadron E resolution	σ_{E_h}/E_h	$\sim 90\%/\sqrt{E_h} \oplus 30\%$

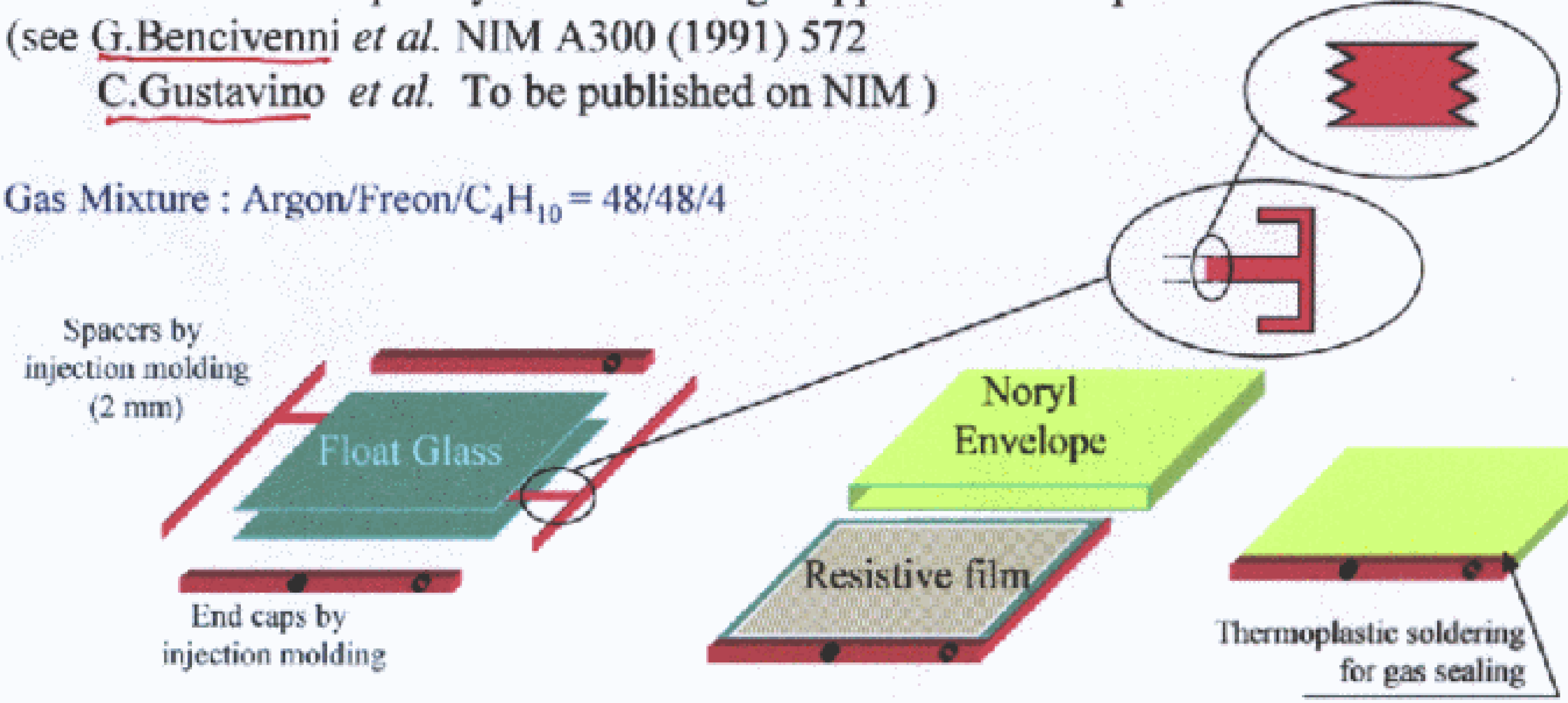


~52000 m² of detector : Glass Spark Counters

Glass Spark Counter I

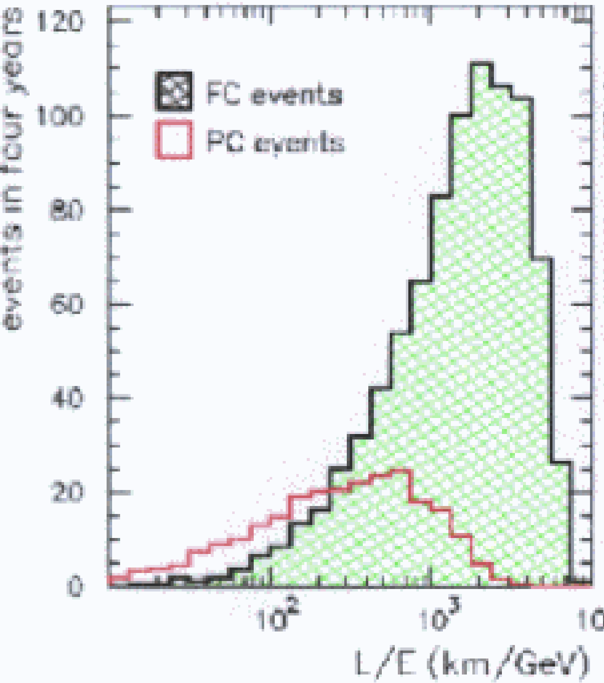
It is an RPC with electrodes made of standard float glass instead of Bakelite with a completely different design approach developed at LNGS.
(see G.Bencivenni *et al.* NIM A300 (1991) 572
C.Gustavino *et al.* To be published on NIM)

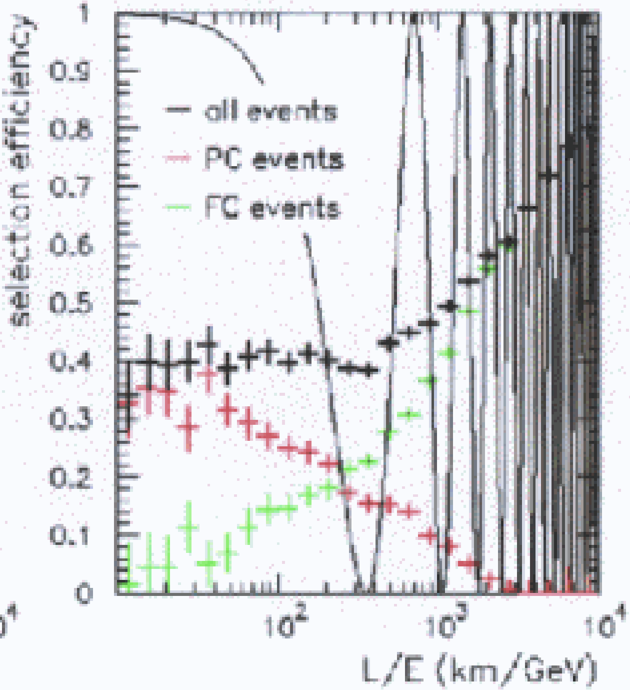
Gas Mixture : Argon/Freon/C_4H_{10} = 48/48/4



Easy and fast and cheap construction
Ready for mass production.

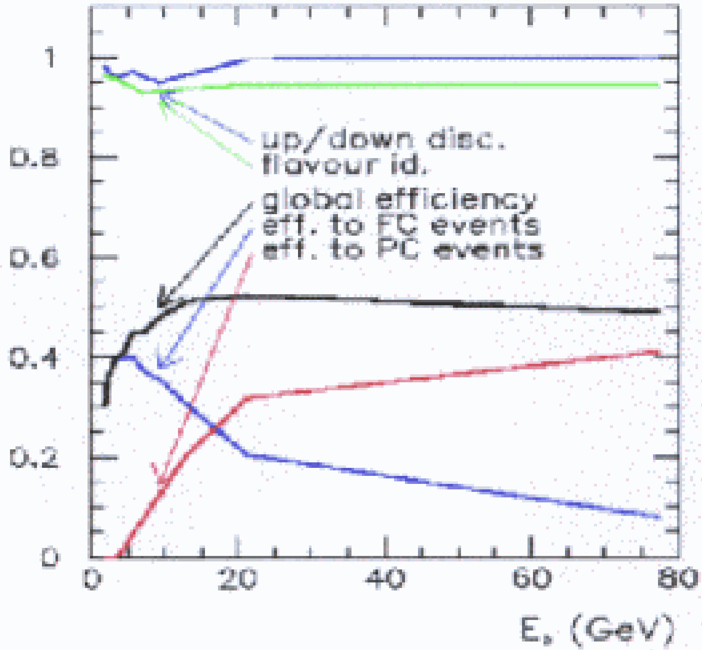
Effect of the Magnetic Field

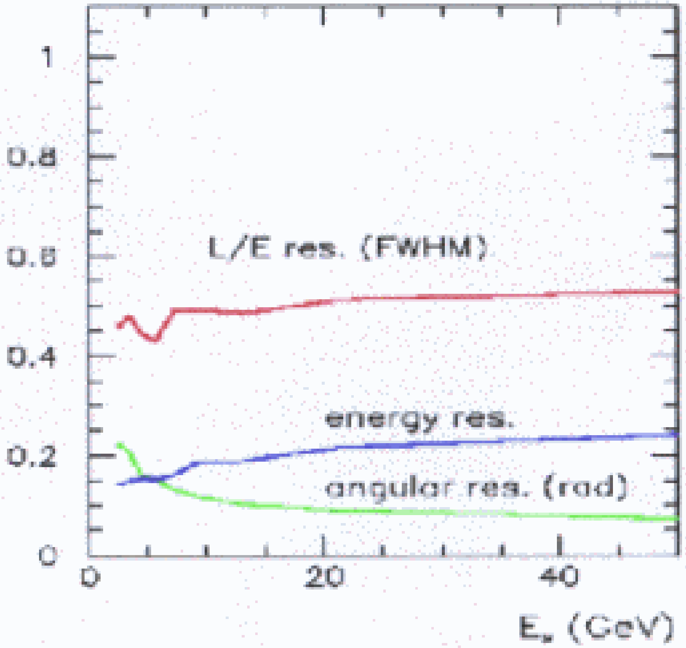




- ☺ Higher efficiency in the low L/E region
- ☺ Higher efficiency in the L/E region of physical interest (10^2-10^3)
- ☹ Slightly higher cost and complexity
- ☹ (anti-seismic rules for LNGS impose expensive mechanics anyway)

Efficiencies and resolutions





Selected ν_μ CC after 4 years of data taking (no oscillation):

Fully contained:	931
Partially contained:	259
Total:	1190

1) ν's oscillations ?

In 4 years Monolith can show the full oscillations swing.

2) Improvement of the measurement of the Parameters.

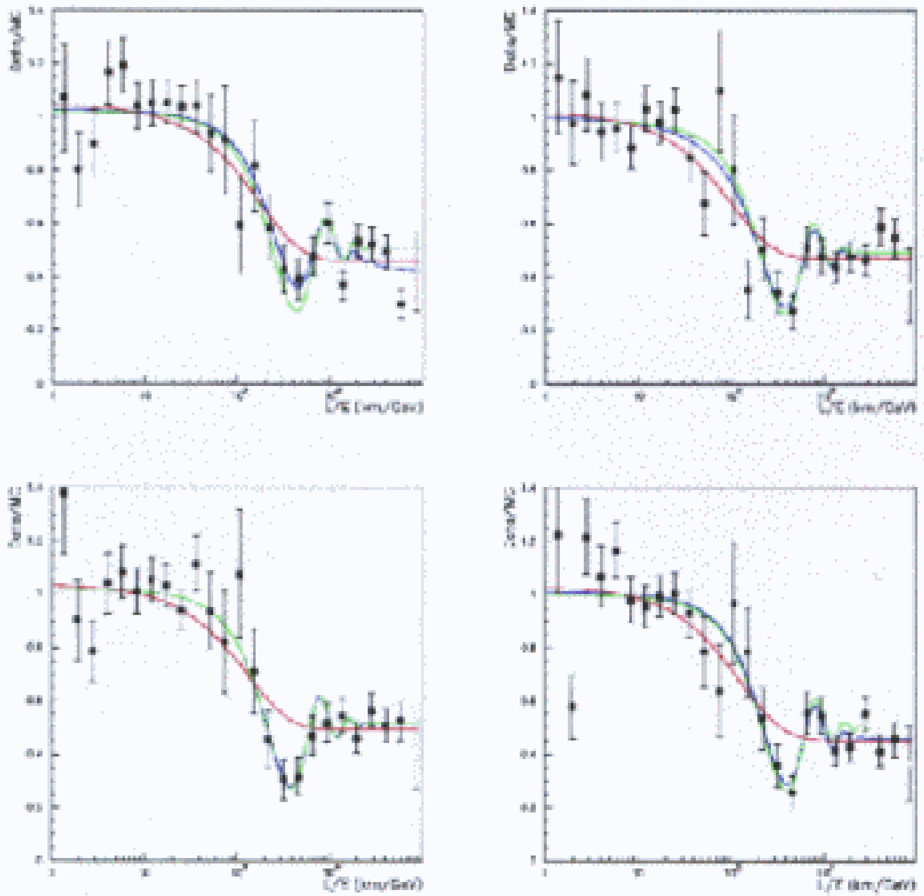
3) ν_τ / ν_s discrimination

-The CNGS beam will cover with very high statistics the region L/E <100 Km/Gev :

- 40.000 events/year ν_μ CC

($\simeq$200 events/year from up-going atmospheric)

Detection of the oscillation pattern



<u>Four</u> simulated experiments of 4 years
$\Delta m^2 = 0.003$ eV^2

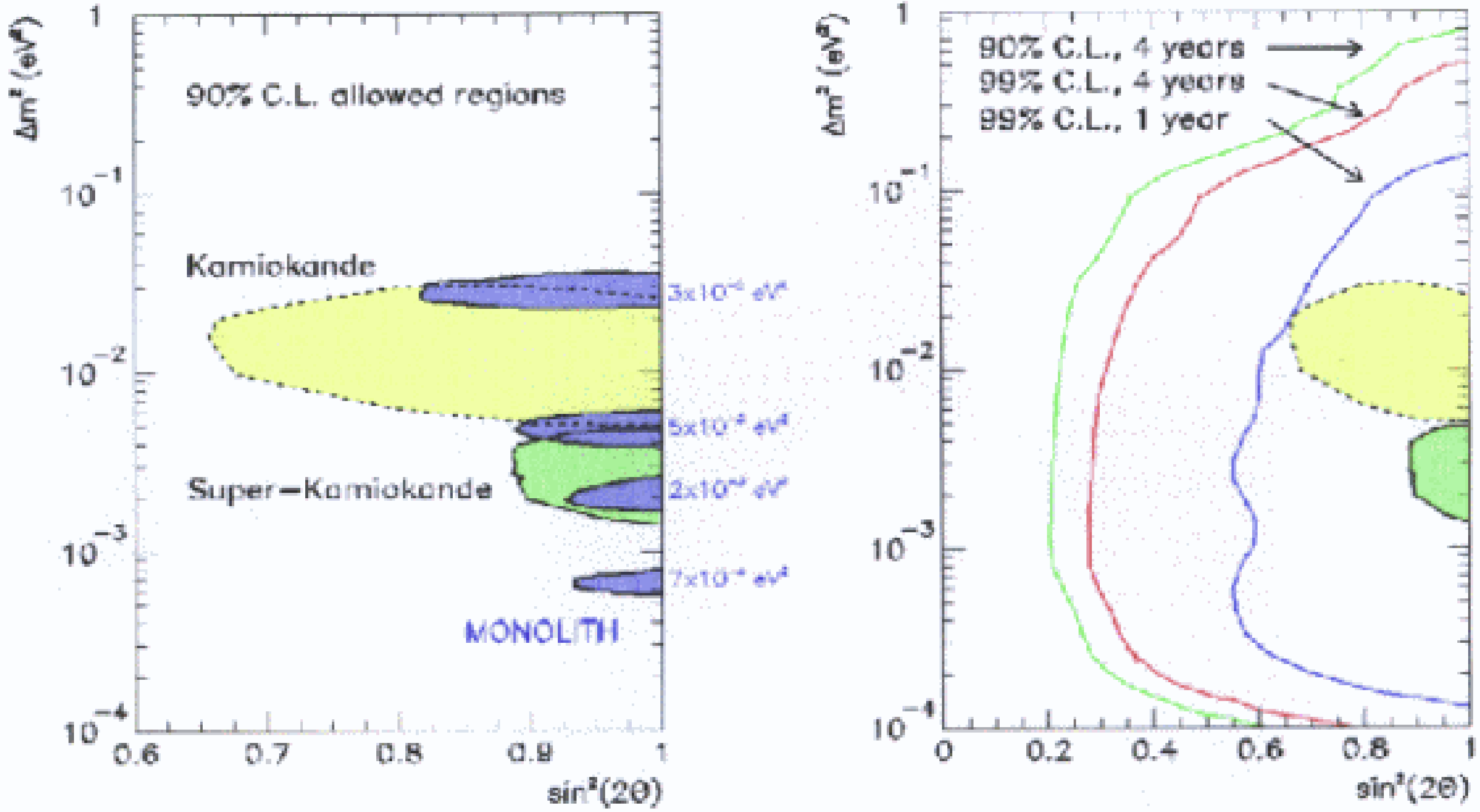
It is shown:

- best parametric fit (free mix of oscillation and decay)
- best fit to oscillation
- best fit to decay

11''

2)

Monolith sensitivity - 4 y



Comparison of MONOLITH sensitivity to oscillations with Kamiokande and SuperKamiokande

- 90% C.L. allowed regions after 4 years for different Δm^2 (left)
- Exclusion regions if no effect is found (right)