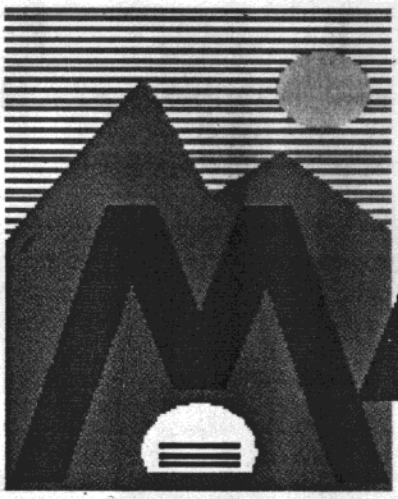
ATMOSPHERIC NEUTRINO RESULTS IN



MACRO at GRAN SASSO

M onopole , **A** strophysics , and **C** osmic **R** ay **O** bservatory

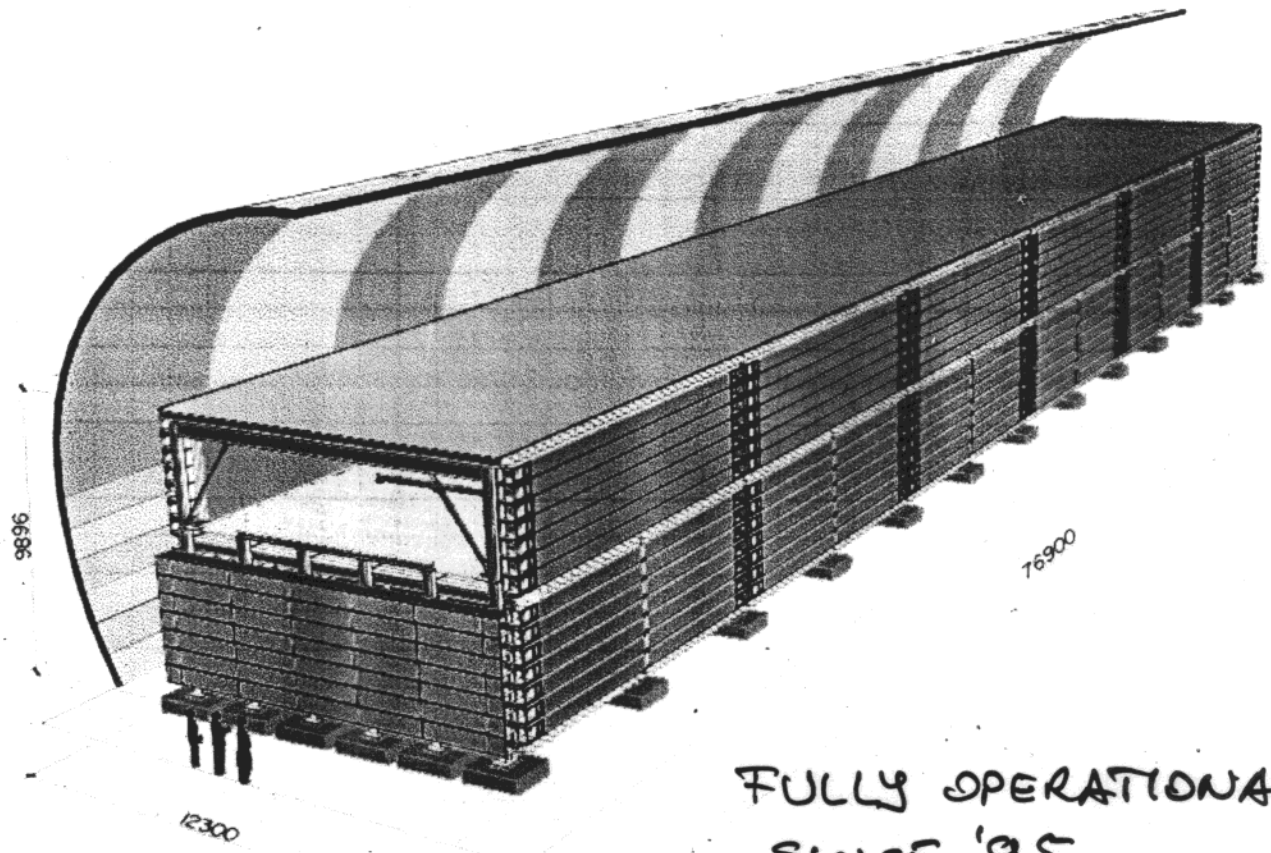
USA-ITALY Collaboration

Bari,Bologna,Boston,Caltech,Drexel,Indiana,Frascati,Gran Sasso,L'Aquila,Lecce,Michigan,Napoli,Pisa, Roma I, Texas,Torino

SUMMARY:

- RESULTS ON UP-THROUGOING μ
- " " SEMICONT. EVENTS
- " " STOPPING UP + SEMIC. DOWN
- DOUBLE RATIO
- CONCLUSIONS

Main features of Macro as ν detector



FULLY OPERATIONAL SINCE '95

- 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.

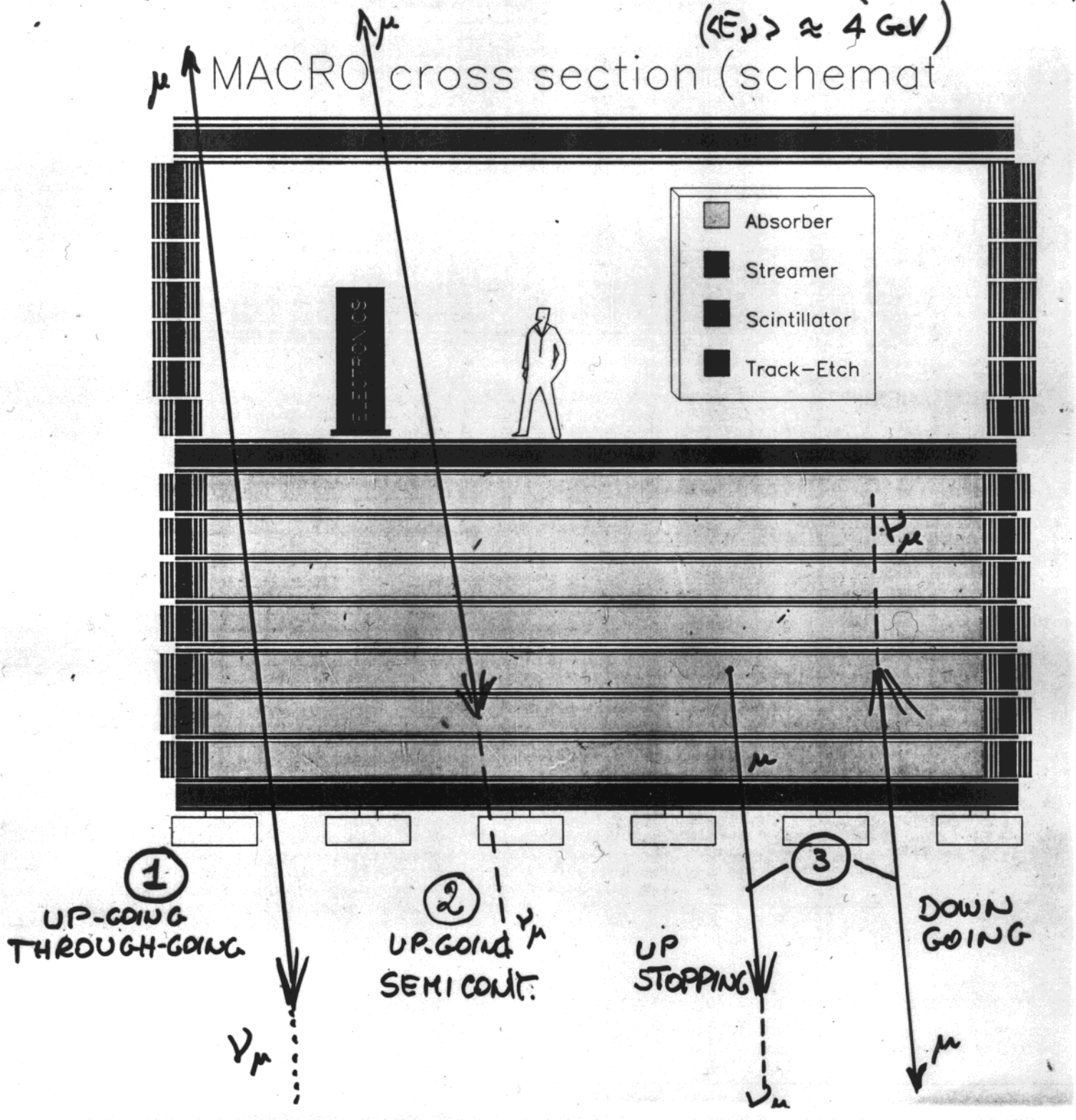
MACRO

3 EVENT CATHEGORIES

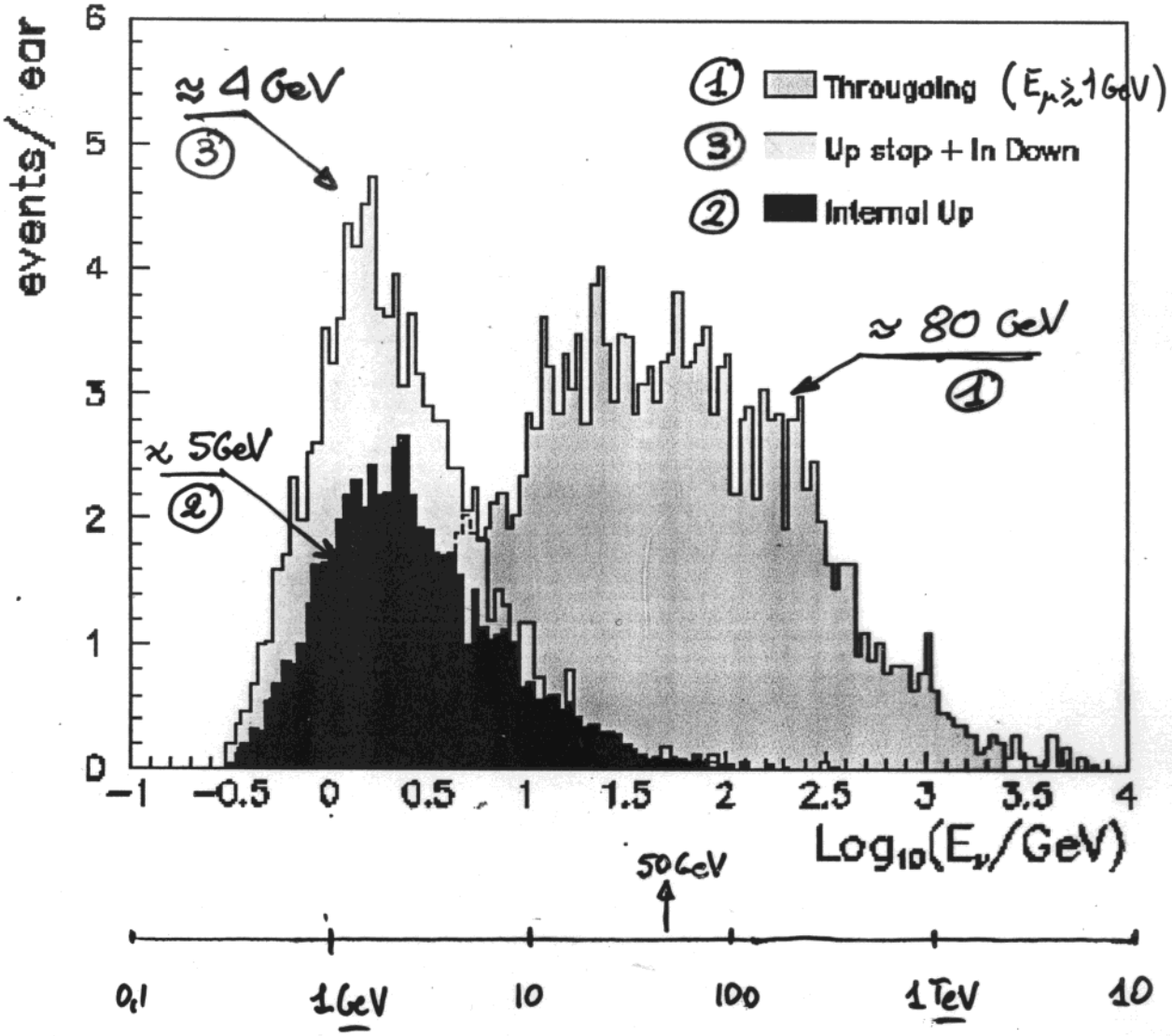
1)- UP-THROUGH GOING ($\langle E_\nu \rangle \approx 80$ GeV)

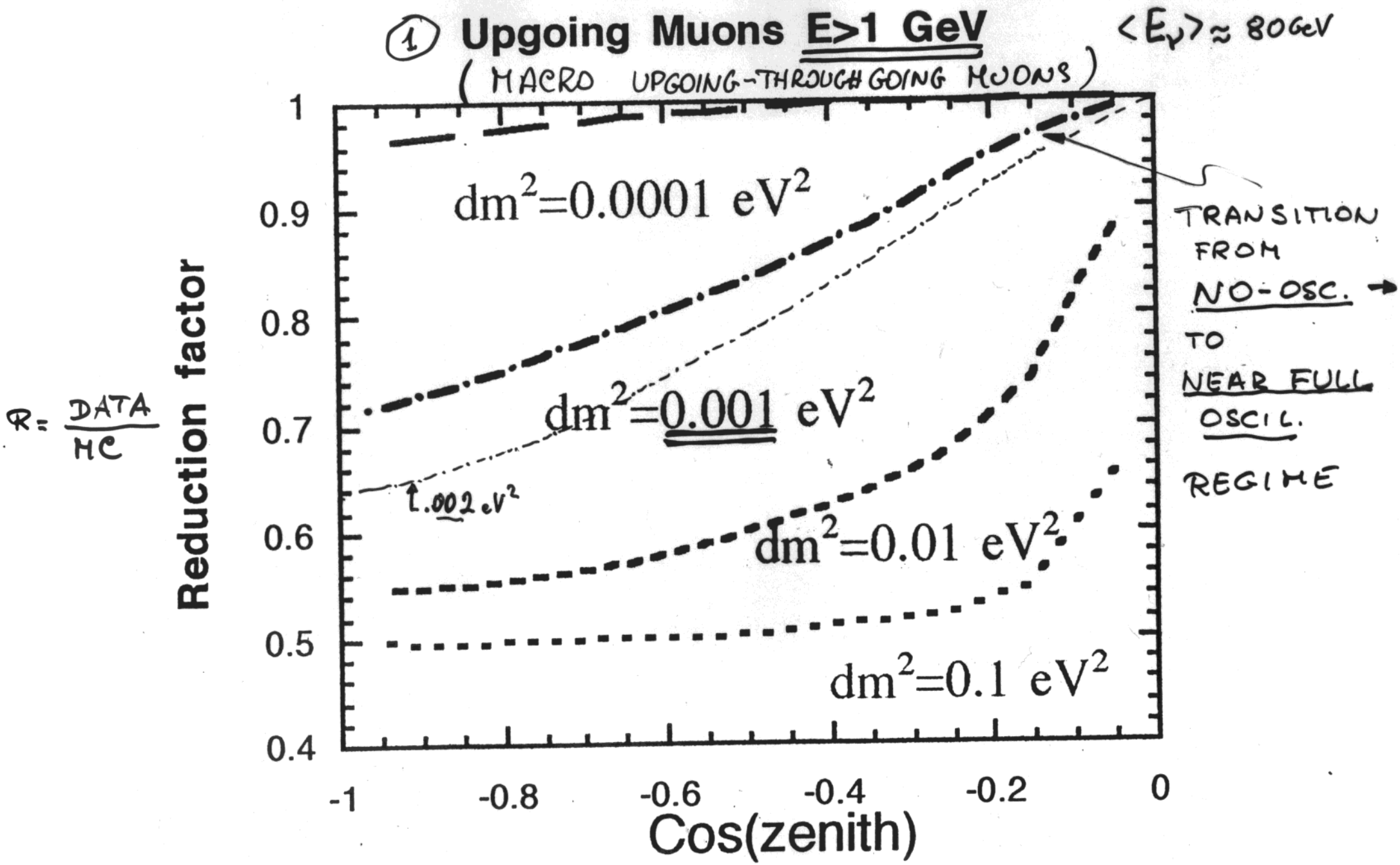
2)- UP. SEMICONTAINED ($\langle E_\nu \rangle \approx 5$ GeV)

3)- UP-STOPPING + DOWN-SEMIC. ($\approx 50\% + 50\%$)
($\langle E_\nu \rangle \approx 4$ GeV)



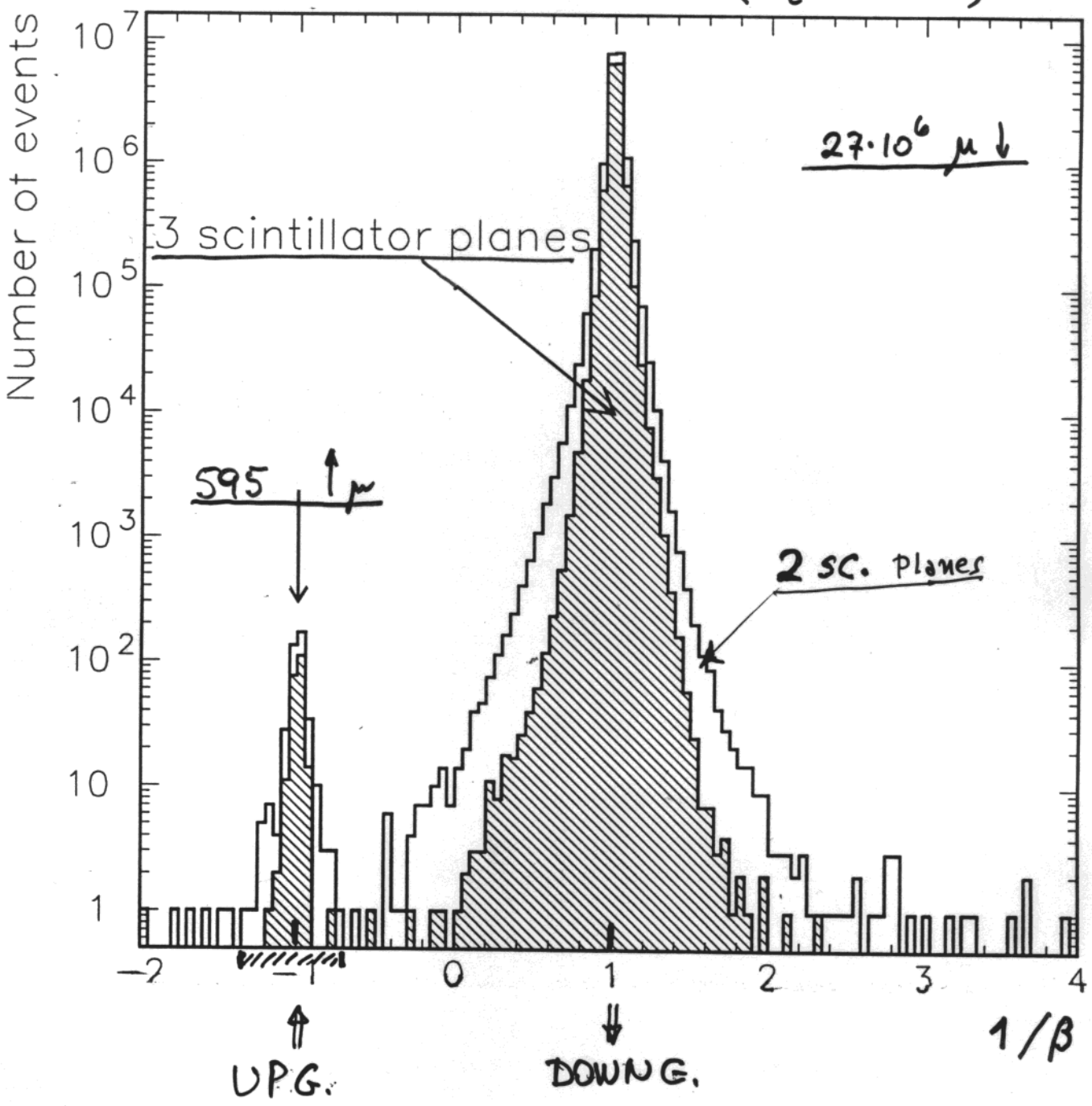
Parent Neutrino Energy for different event topology




① Upgoing Muons E>1 GeV
<Eν> ≈ 80GeV
(MACRO UPGOING-THROUGH GOING MUONS)
Reduction factor
R = DATA / MC
1
0.9
0.8
0.7
0.6
0.5
0.4
dm²=0.0001 eV²
dm²=0.001 eV²
1.002 eV²
dm²=0.01 eV²
dm²=0.1 eV²
TRANSITION FROM NO-OSC. TO NEAR FULL OSCIL. REGIME
-1
-0.8
-0.6
-0.4
-0.2
0
Cos(zenith)

(1) UPGOING - THROUGHGOING MUONS

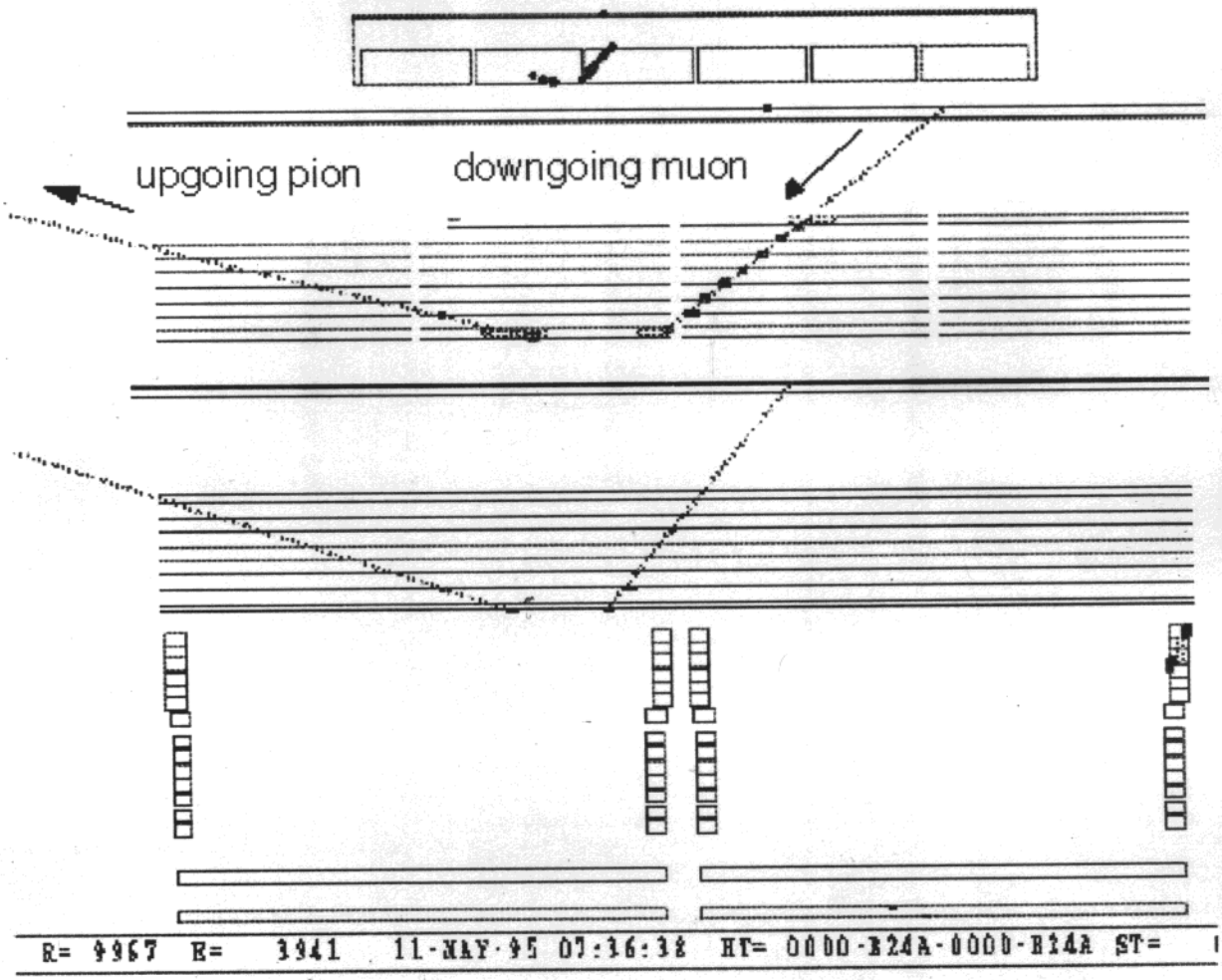
EVENT SELECTION BY T.O.F. TECH.
($\sigma_t \simeq 0{,}5$ ns)



Pion production at large angle

- Pions produced at large angle from muon interaction in the rock around the detector are a possible source of background for stopping and throughgoing upgoing muons
- 243 upgoing particles + downgoing muons were found in 13.600 h

background in the stopping muon search (5%)
and in the through-goind (2%)



RATE $\approx 10^{-5}$ * ↓ MUONS

① UP-THROUGH-GOING μ

- DATA UP TO DIC '97 (479 ev.) ← ν' 98, NOW '98... ← PUB. ON P.L.
- ANALYSIS UPDATED TO OCT '98 :
  (TOTAL LIVE TIME 4.3 y)

μ↑ EVENTS		595
SUBT.:	- WRONG β	12.5
	- "BACK SOFT π" (PHOTONUCL. μ INT.) 	9.8
	- SEMI CONTAIN. EVENTS (NOT INCLUDED IN M.C.)	13.3
		559.4 EVENTS

EXPECTED EVENTS BY MC 742.5 EVENTS

(BARTOL FLUX + { ν X-SECTION, "STRUC FUNC." })

ESTIM. "THEOR" UNCER. ±17%
(MOSTLY CONSTANT WITH θ)

$$R = 0.75 \pm 0.03_{\text{STAT}} \pm 0.05_{\text{SYS}} \pm 0.13_{\text{THEOR}}$$

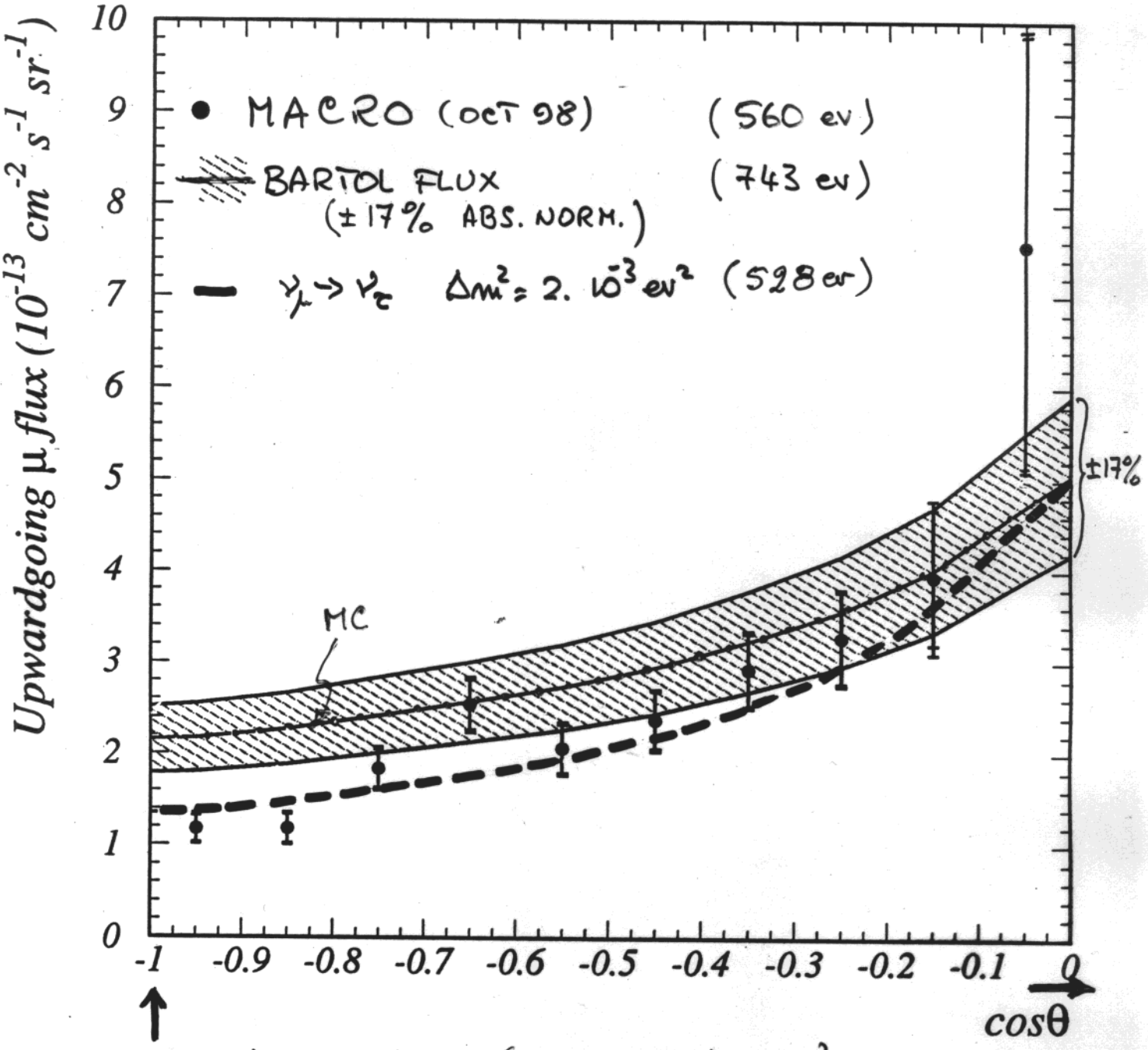
TEST OF CHANGING THE "STRUC FUNC" R = 0,75 → 0,72

MORE IMPORTANT : SHAPE OF θ DISTR.

ANGULAR DIST. OF UP-THROUGH. μ

$E_\mu > 1$ GeV $\langle E_\nu \rangle \approx 80$ GeV

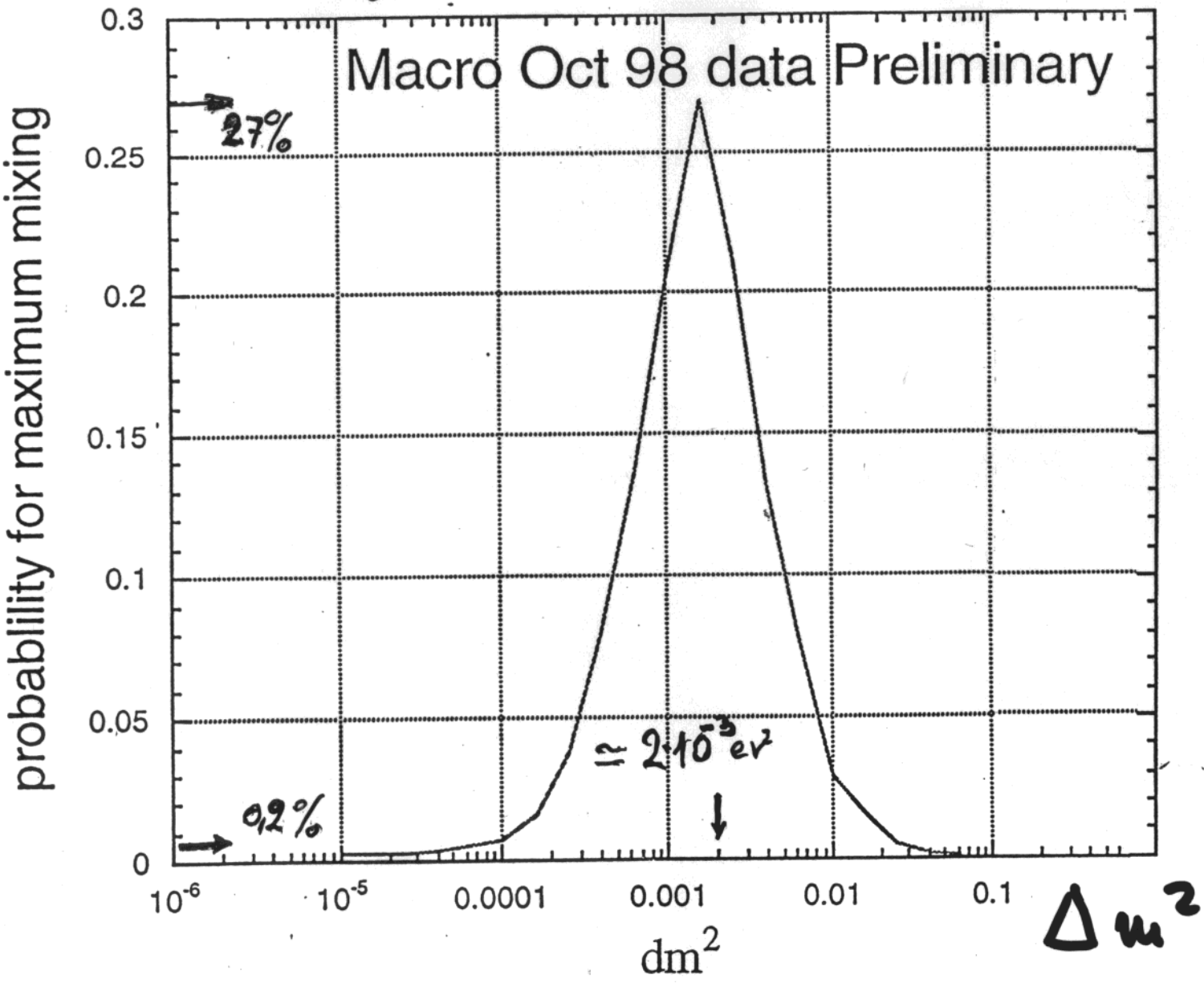
EXPOS. ≈ 4.3 y (live time)



NO OSCIL. (NORM FREE) $\chi^2 = 24/8$

OSCIL. (") $\chi^2 = 14/8$

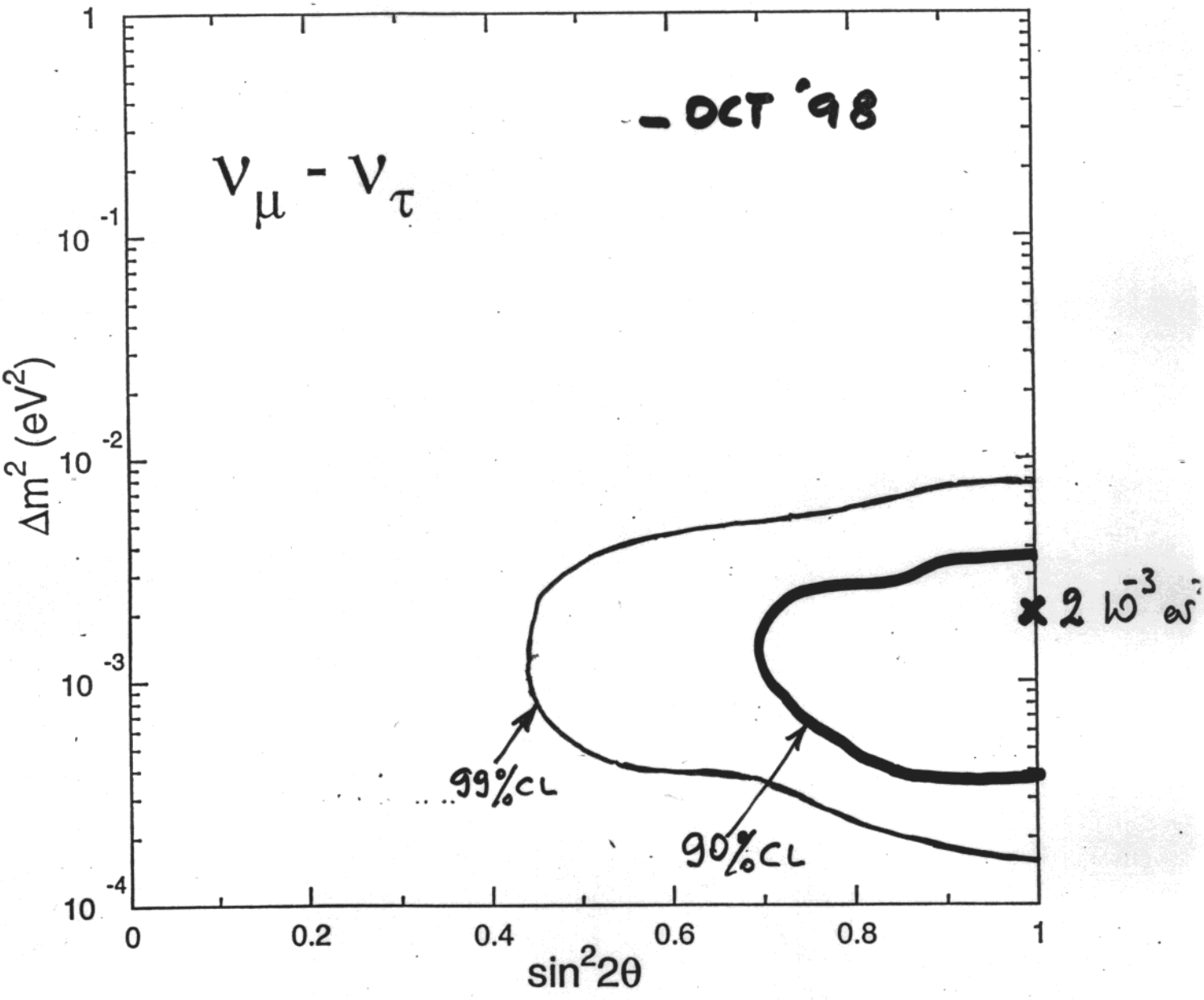
UPGOING MUONS



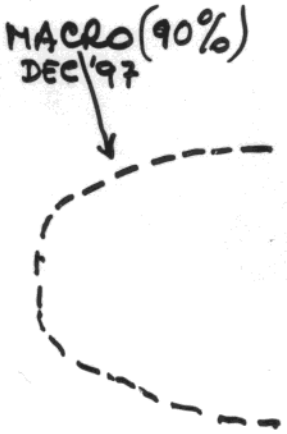
COMBINED
SHAPE
+
NORM.
FIT

MACRO ALLOW. REGION

(FELDMAN-COUSINS METHOD)

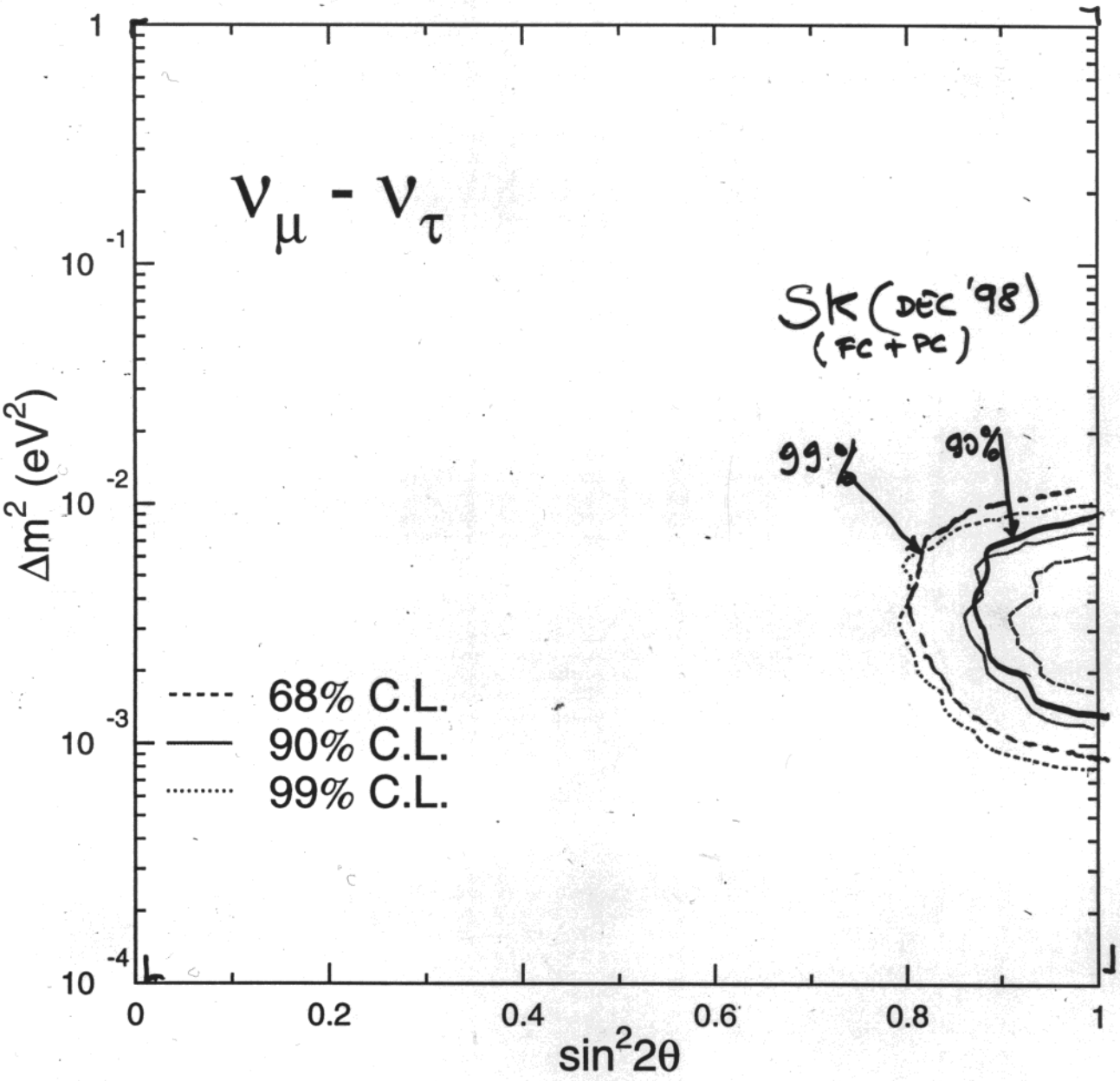


- DEC '97



(19)

Super-Kamiokande 736 days FC + 685 days PC Preliminary



② SEMICONTAINED EVENTS

$\langle E_\gamma \rangle \simeq 5$ GeV

FROM MC $\sim 89\%$ DUE TO ν_μ

DATA UP TO DIC '97 — 88 EVTS — ν'98, NOW... hep 9809003 ,, 9808001

ANALYSIS UPDATED TO OCT '98 — 108 EVTS

BKG. SUB. (WRONG β) — 4 "

104 EVTS

EXPECT. BY MC (NO OSCILL) 187 evts (±47)

(BARTOL FLUX + LOW E XSECTION...)

THEORET. UNCER. ±25%

PARTIALLY CORR. WITH $\mu\uparrow$ FLUX UN.

$$R = 0.56 \pm 0.06_{\text{Stat}} \pm 0.06_{\text{SYS}} \pm 0.14_{\text{THEOR}}$$

R EXPECTED WITH OSCIL. IN MC ($\Delta m^2 = 2 \times 10^{-3}$ eV^2)

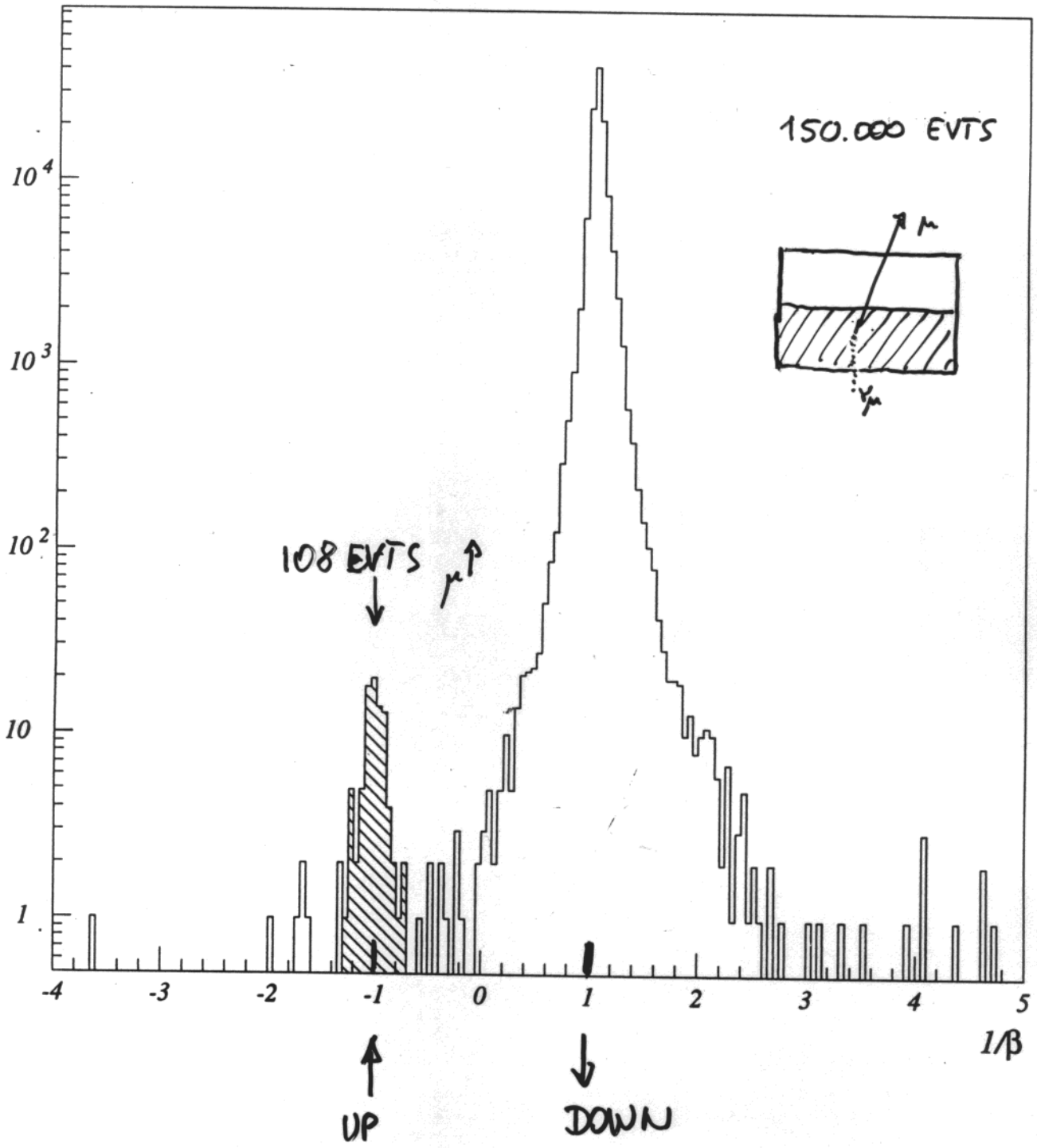
$$R = \frac{MC_{OSC}}{MC_{NOOSC}} = \frac{108}{187} = 0.58$$

FULLY OSCILL. REGIME:

SAME SHAPE AS NON-OSCIL, REDUCED # EVTS

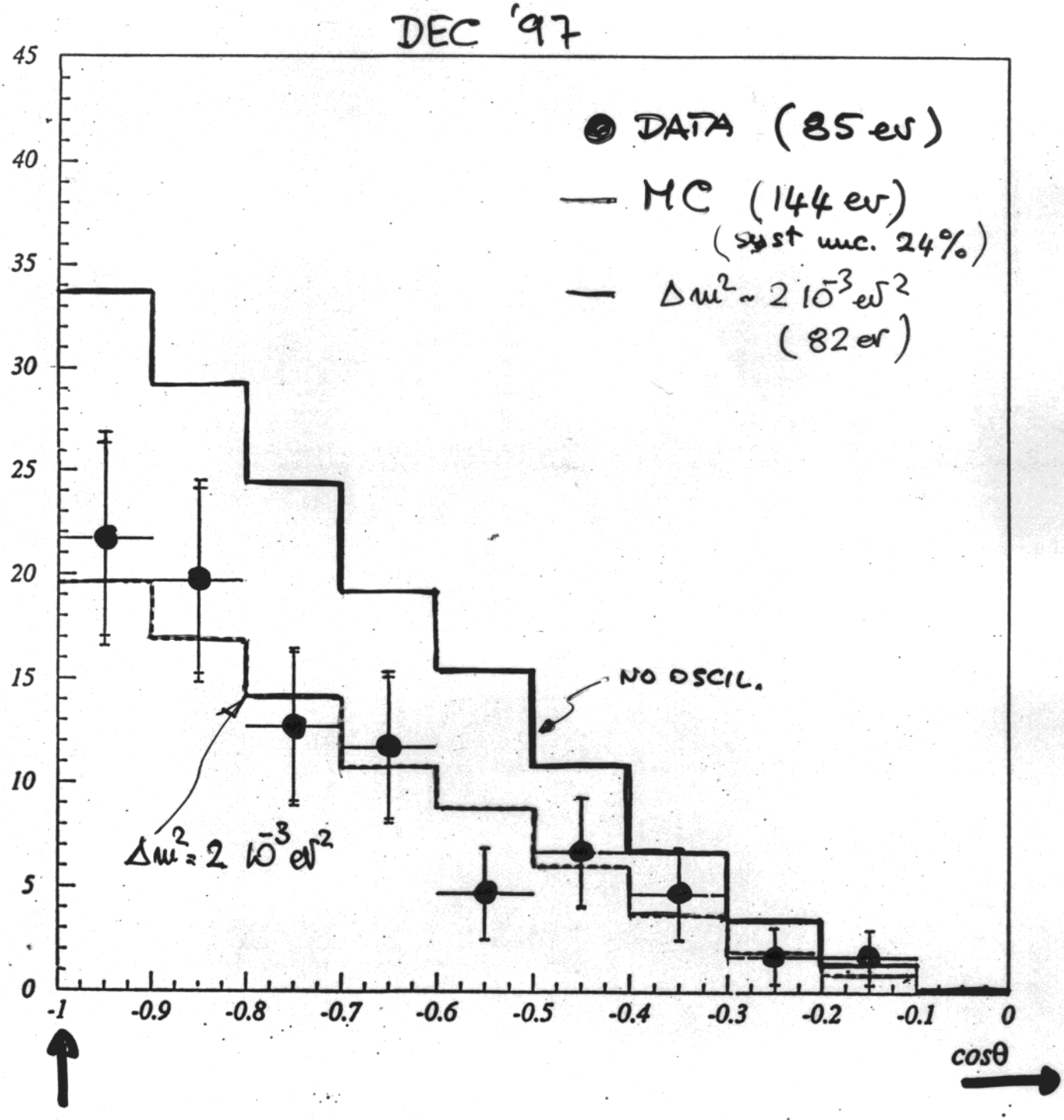
$$10^{-4} \lesssim \Delta m^2 \lesssim 10^{-2} \text{ eV}^2$$

SEMICONTAINED EVENTS



Internal Upgoing muons:

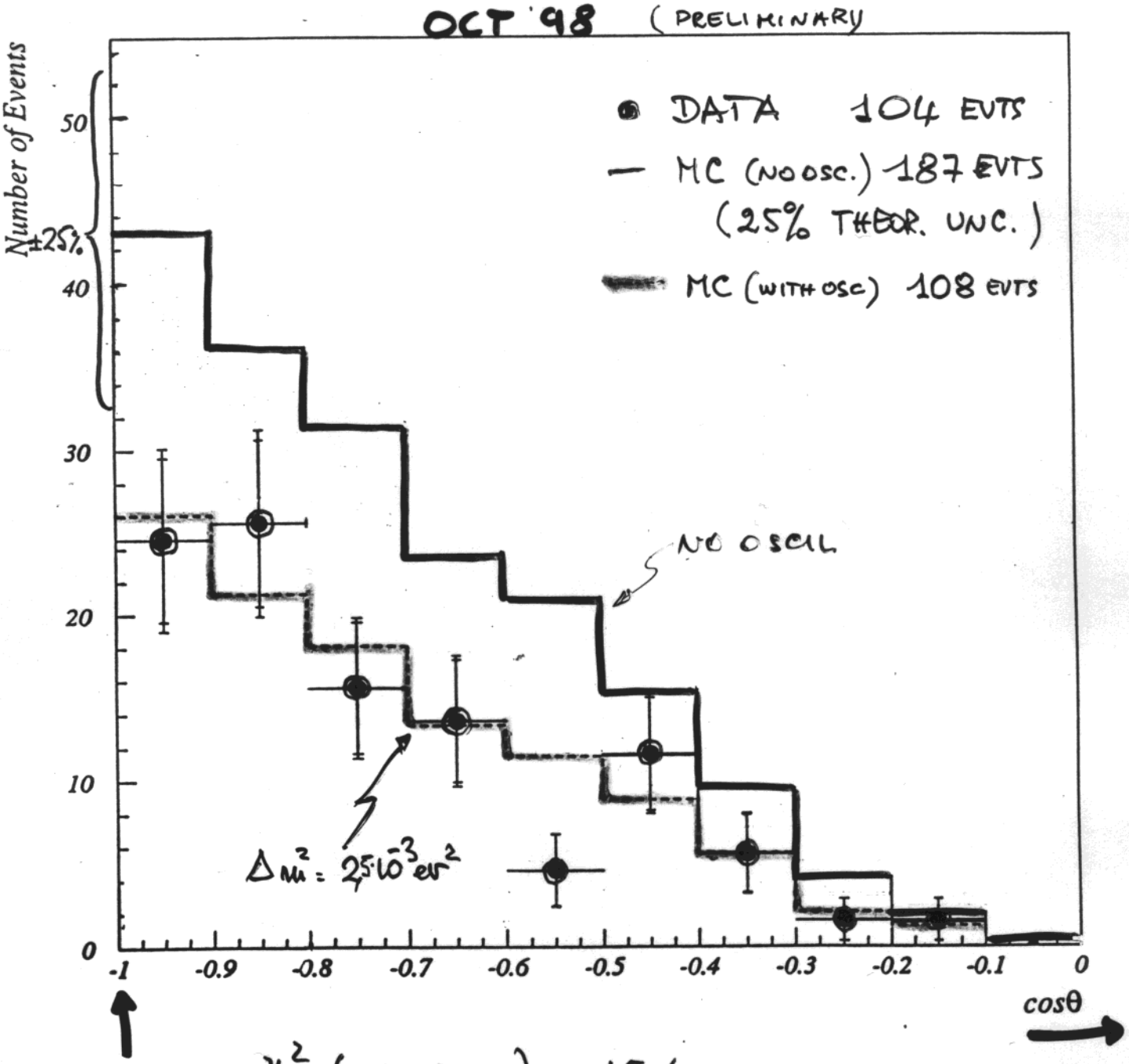
($E_\nu \approx 5$ GeV)



SEMI CONTAINED EVENTS

$\langle E_\nu \rangle \simeq 5$ GeV

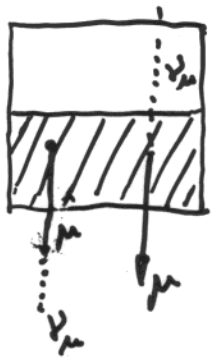
LIVETIME $\simeq$ 4 y



χ^2 (NO OSCIL) = 15/8

χ^2 (CON OSCIL) = 7/8

(3) UPGOING STOPPING
+
SEMICONT. DOWNGOING



- MIXTURE OF 50% ↑ + 50% ↓
- FROM MC : 87% DUE TO ν_μ
- DATA UP TO DIC '97 122 evts — ν 98, NOU / hep 9808001 / " 9809002
- ANALYSIS UPDATED TO OCT '98 (BKG SUBTR.) 162 evts
- EXPECT BY MC (NO OSCIL.) 225 evt
  (BARTOL FLUX + LOW E XSECTION)
  THEOR. UNCER. 25%
  (PART CORR. WITH $\mu\uparrow$ FLUX
  WELL CORR WITH SEMICON. FLUX)

$$R = 0.72 \pm 0.06_{\text{stat}} \pm 0.08_{\text{syst}} \pm 0.17_{\text{THEOR}}$$

R EXPECT WITH OSCILL. IN MC ($\Delta m^2 = 2.5 \cdot 10^{-3}\ eV^2$)

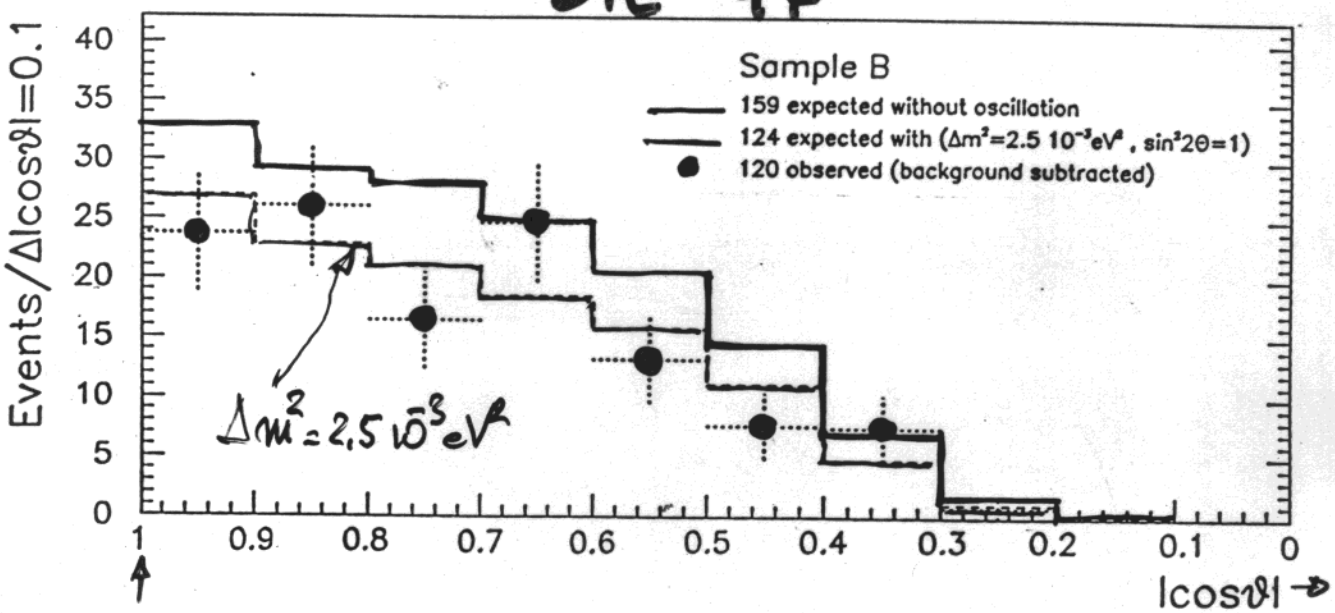
$$R = \frac{MC_{osc}}{MC_{noosc}} = \frac{178}{225} = 0.79$$

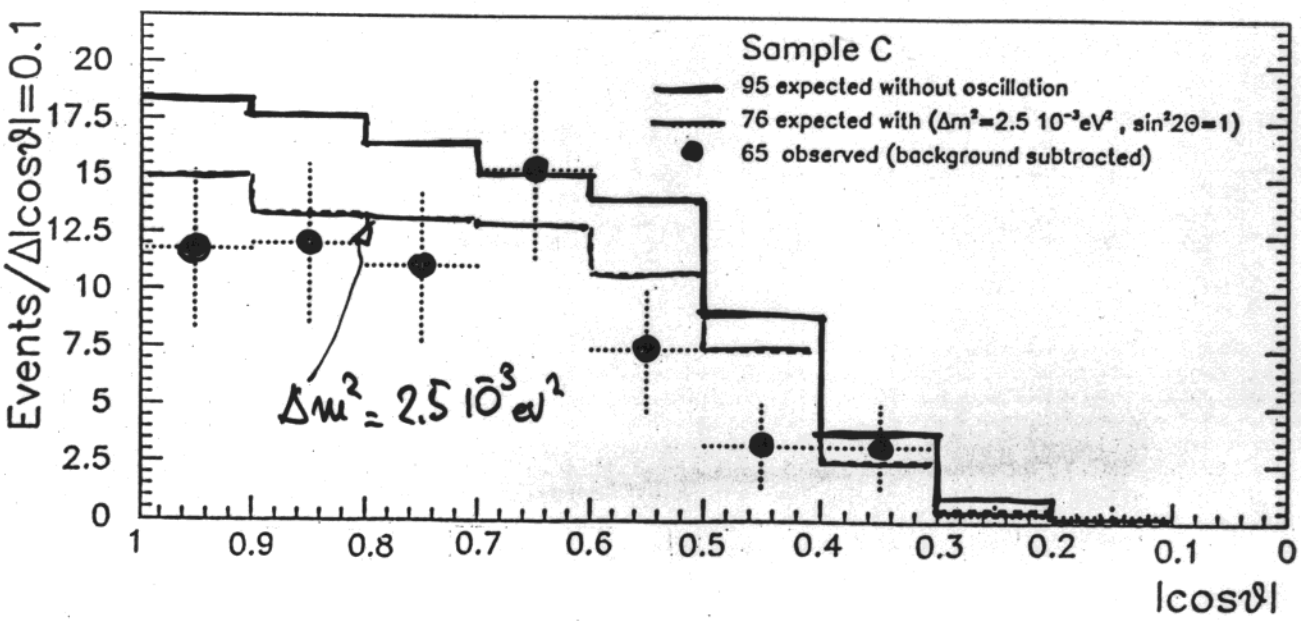
FULLY OSCILL. REGIME
SAME SHAPE, REDUCED # EVTS

Downgoing internal muons
+
Stopping upgoing muons

$E_\nu \approx 4$ GeV

DIC '97

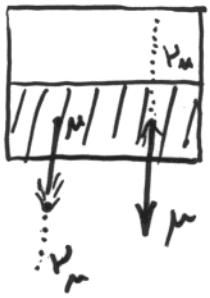


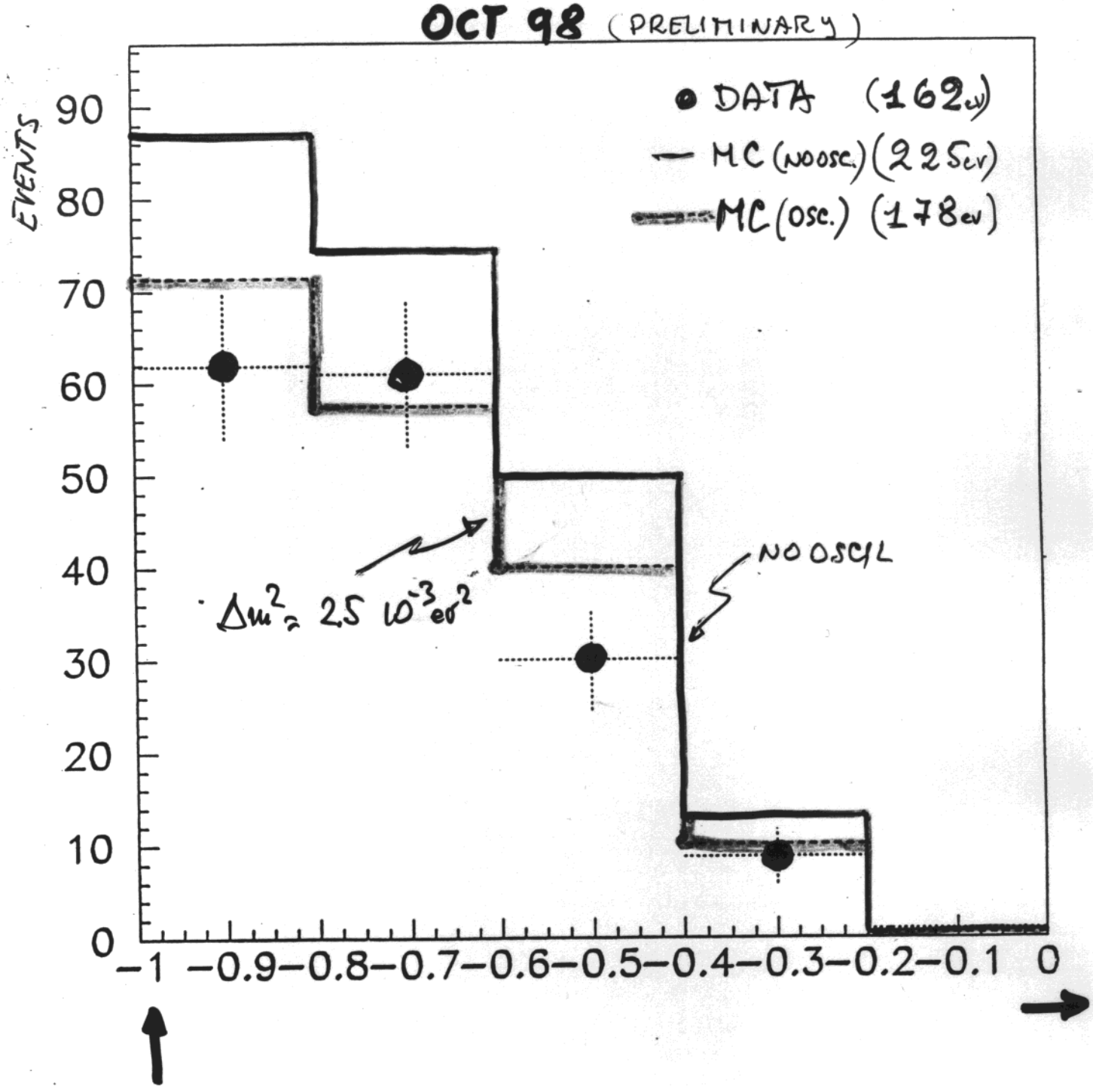


(3) UPGOING STOPPING (≈ 50%)
+
SEMICONT. DOWNGOING (≈ 50%)

$\langle E_\nu \rangle \simeq 4$ GeV

LIVETIME = 3.6 y





- APPROCH FOR REDUCING THE UNCERT. ON ν FLUX :

$$\text{DOUBLE RATIO} = \frac{\frac{\text{SEMICONT. EV.}}{MC_{SEM.}}}{\frac{\text{STOP + DOWN.}}{MC_{S+D}}}$$

NO OSC 1

OSC <1

- E_ν RANGE VERY SIMILAR

"THEOR UNCERT" 25% $\longrightarrow \sim 0$

- REDUCED SYSTEM. ON ANALYSIS

PRELIMINARY RESULTS

$$R_R = 0,77 \pm 0,16$$

EXPECTED WITH NO OSCIL. 1

EXPECTED WITH OSCILL. 0,73

$(\Delta m^2 \simeq 2,5\,10^{-3}\,eV^2)$

CONCLUSIONS

- RESULTS FROM 3 EVT. CATEG. :

1) UP-THROUGH GOING μ

- AVERAGE R : 0.75 ± 0.06 (st.+sys)
- SHAPE DISTORTED : R RANGING 50 % (VERT) → 100 % (HORIZ)

(DISTOR. ALWAYS PRESENT SINCE TAUP'93)

- PROPABILITY FOR NO OSCIL 0.2 %
- " FOR $\nu_\mu \to \nu_\tau$ 27 %

AT $\Delta m^2 \simeq 2 \cdot 10^{-3}\ eV^2$, $\sin^2 2\theta = 1$

2) SEMI CONTAINED EVTS

- AVERAGE $R = 0.56 \pm 0.09$ (st+sys)
- SHAPE OK

3) STOPPING UPGOING + SEMIC. DOWNG.

- AVERAGE $R = 0.72 \pm 0.10$ (sta+sys)
- SHAPE OK

- ALL R COHERENT WITH THE OSCILL. WITH Δm^2 OF $\uparrow\mu$

	R_{MEAS}	$R_{NO\,OSC}$	R_{OSC} ($2\,10^{-3}\,eV^2$)
$\uparrow\mu$	0.75	1	0.73
SEMIC.	0.56	1	0.58
STOP+ DOWN	0.72	1	0.79
R_R	0.77	1	0.73

NEXT STEPS:

- PERFORM A STATISTICAL COMBINED ANALYSIS OF THE 3 RESULTS
- FURTHER REDUCE THE UNCERTAITIES BOTH "THEORETICAL" (FLUX, σ, S.F....) AND SYSTEMATICS (SIMULAT., DETEC. EFFECTS)
- INCREASE STATISTICS IN ORDER TO CONSOLIDATE THE RESULTS OBTAINED UP TO NOW

WARNING:

- THE SHAPE OF Φ_μ NOT WELL FITTED BY MC WITH OSC. ($P \simeq 8\%$)

"DEFORMED" AT $\cos\theta \approx -0.6$:

STATISTICAL FLUCTUATION OR A MORE COMPLEX SCENARIO ?

ANG. DISTRIB. OF $\mu\uparrow$

(OCT '98 DATA)