THE LAKE BAIKAL EXPERIMENT: status and selected results.

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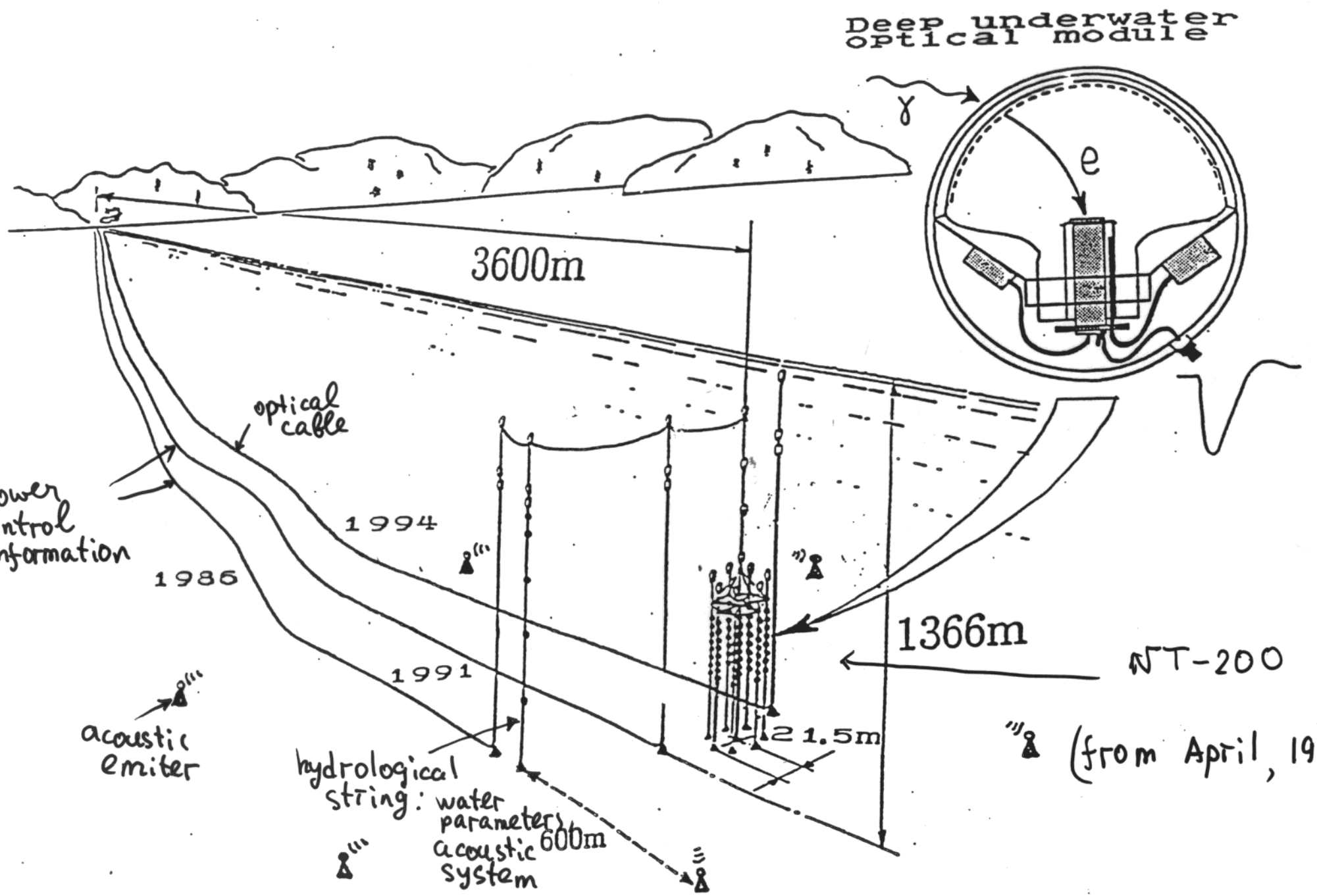
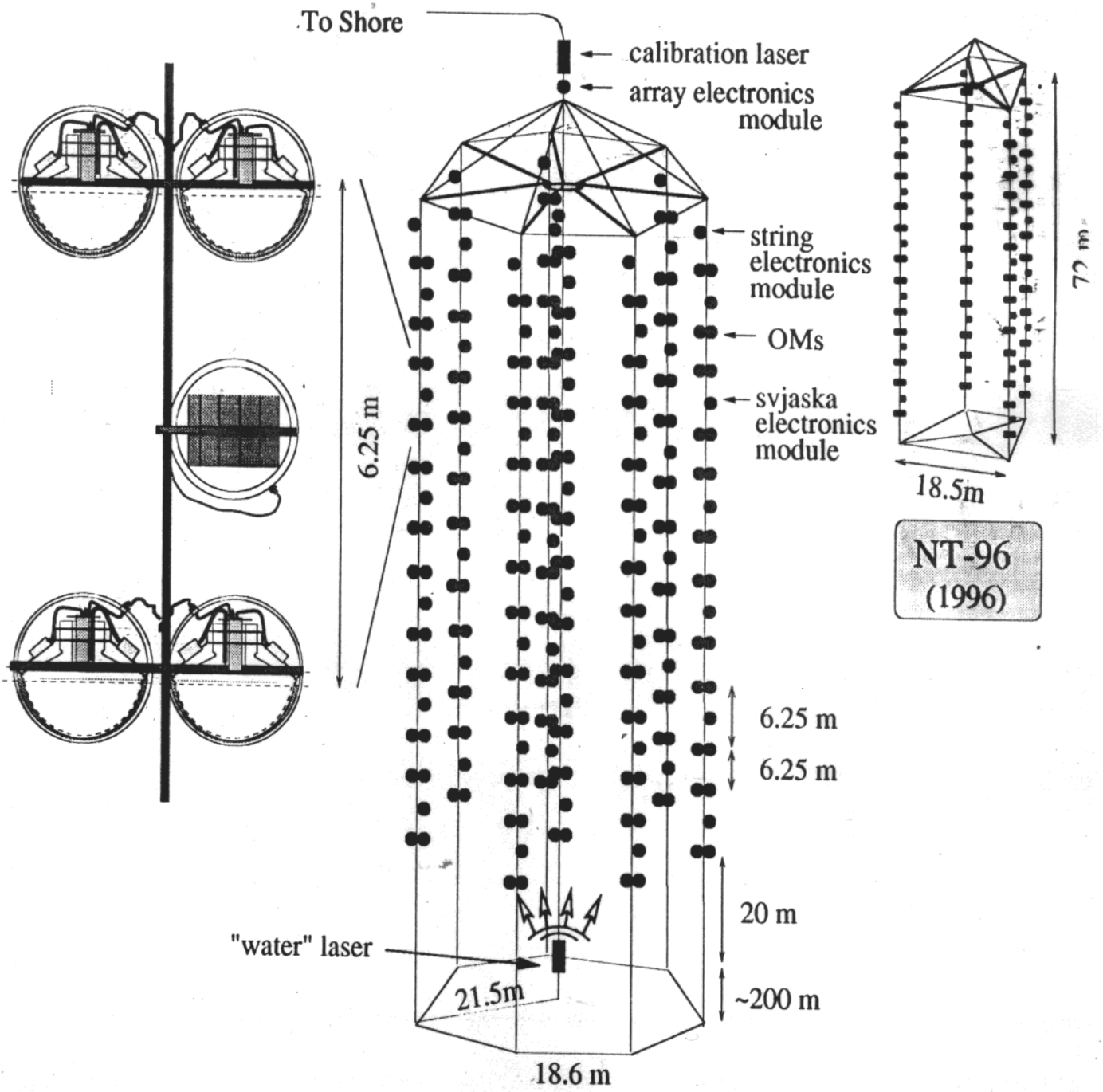

Deep underwater optical module
γ
e
3600m
optical cable
power control information
1994
1986
1991
1366m
NT-200
acoustic emiter
hydrological string: water parameters acoustic system
600m
21.5m
(from April, 199


To Shore
calibration laser
array electronics module
string electronics module
OMs
svjaska electronics module
6.25 m
6.25 m
6.25 m
20 m
~200 m
"water" laser
21.5m
18.6 m
72 m
18.5m
NT-96
(1996)

April 1998 – NT-200

Number of PMT's – 192 ⇒ 96 channels
(37cm QUASAR)

Number of strings – 8

'muon trigger' ⇒ $N_{hit} \geq 4$ within ~500ns

track reconstruction ⇒ ≥ 6/3

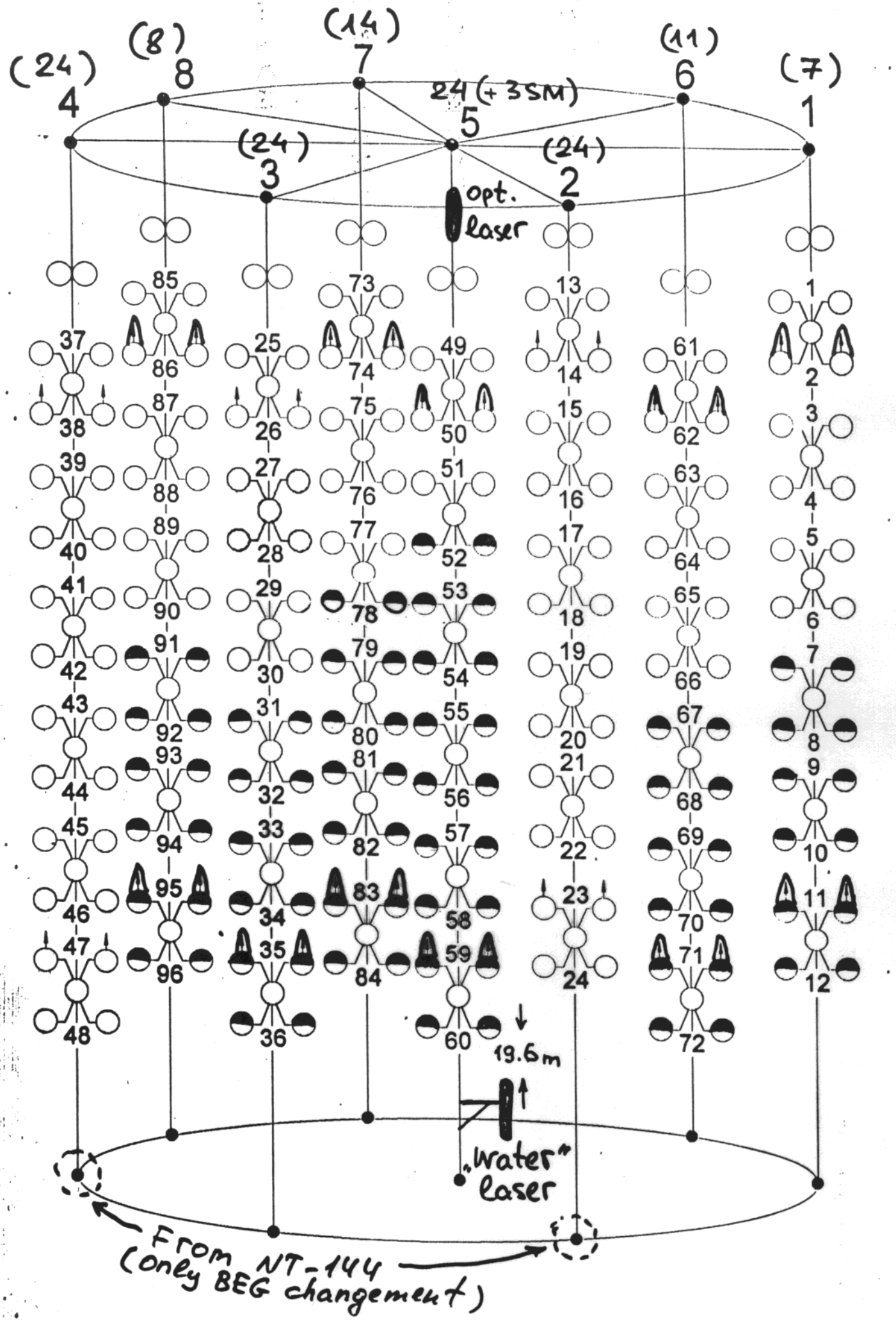
Effective area – $1000 \div 5000\ m^2$

ν_{atm} induced muons ~1/day

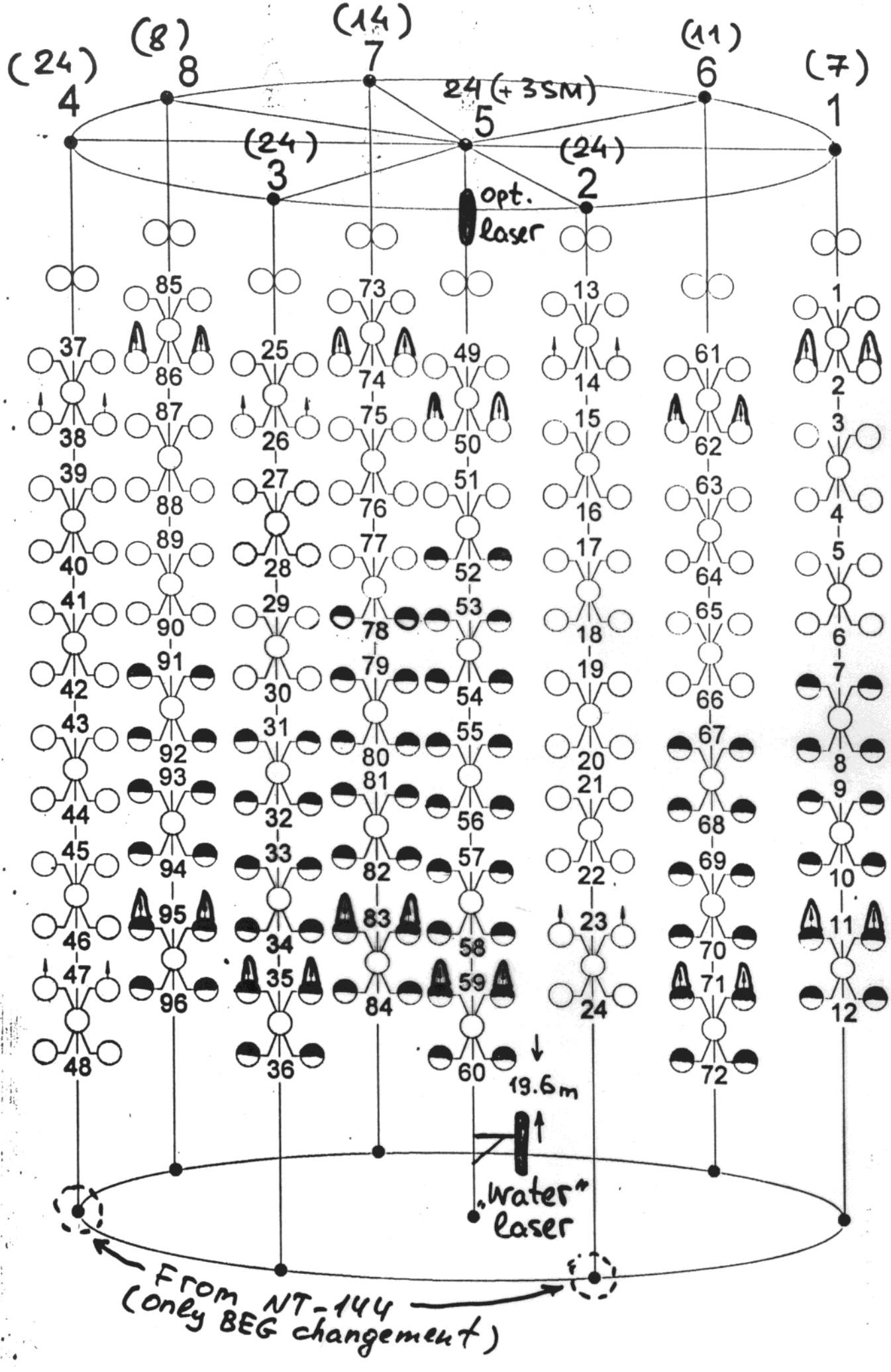
HISTORY

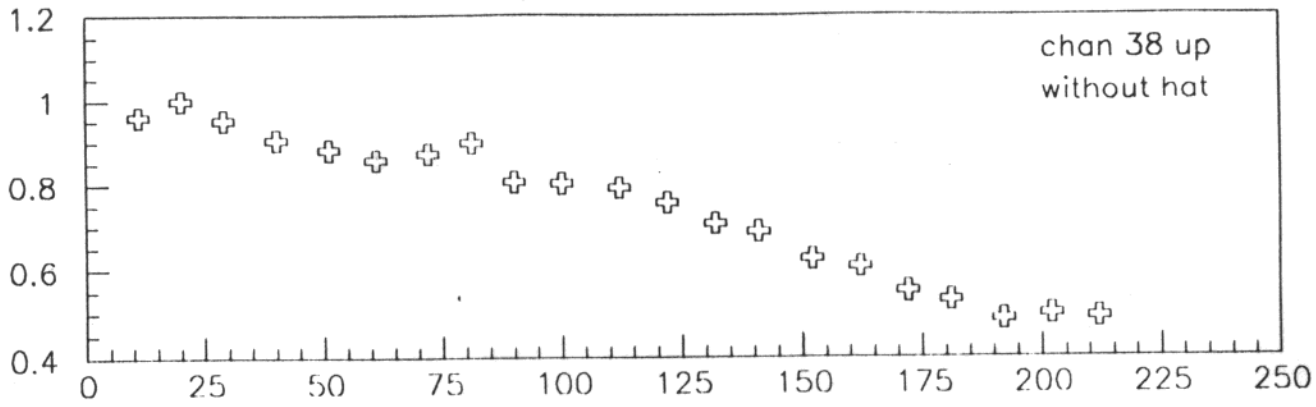
1993 – 1995	– NT-36	(Astr.Ph. 7(1997))
1995 – 1996	– NT-72	
1996 – 1997	– NT-96	(submitted to Astr.Ph.)
1997 – 1998	– NT-144	
1998 –	– NT-200	

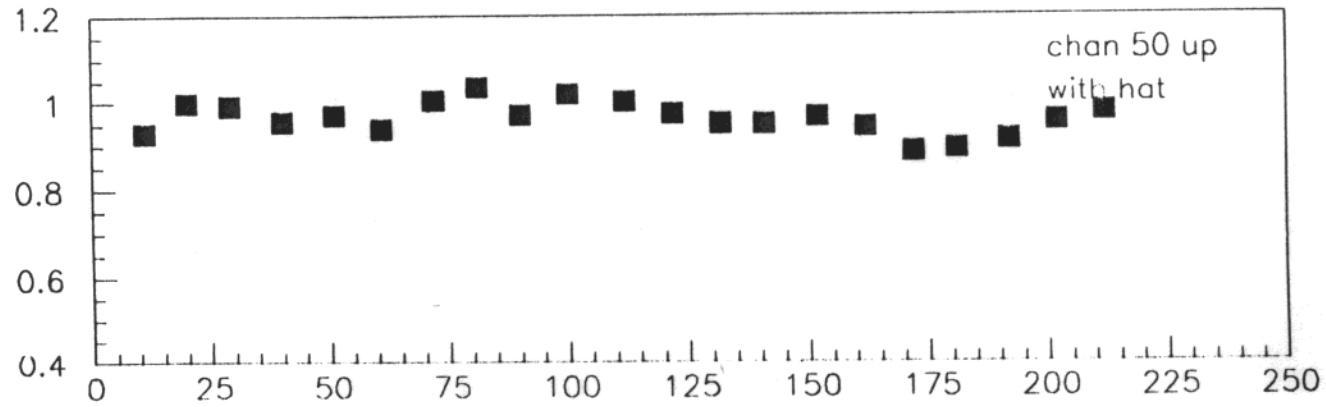
Old "OM from NT-144 → NT 200 →

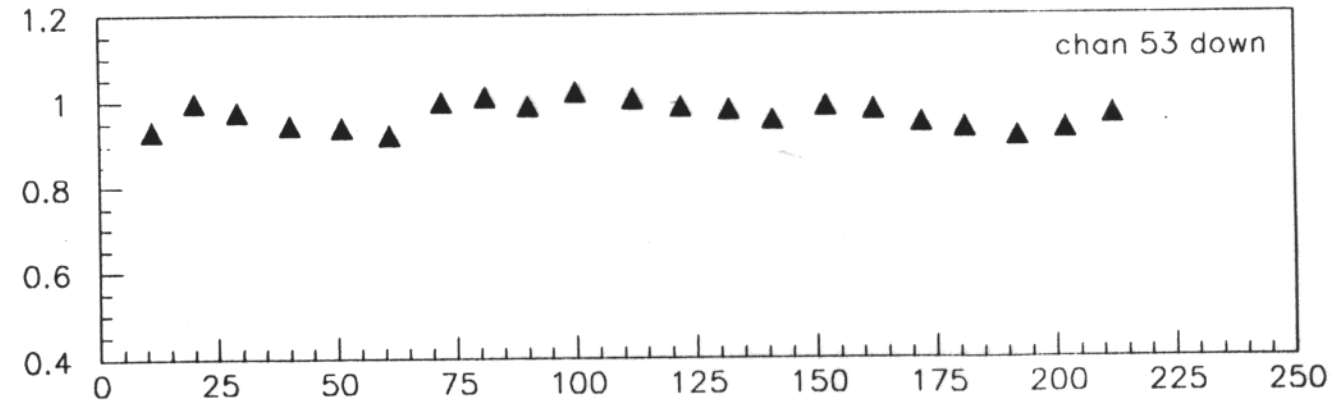


„Old" OM from NT-144 → NT 200 →




chan 38 up
without hat
1.2
1
0.8
0.6
0.4
0
25
50
75
100
125
150
175
200
225
250


chan 50 up
with hat
1.2
1
0.8
0.6
0.4
0
25
50
75
100
125
150
175
200
225
250


chan 53 down
1.2
1
0.8
0.6
0.4
0
25
50
75
100
125
150
175
200
225
250

SELECTED RESULTS

NT-96: 70 days (April ÷ September 1996).

'muon trigger' $\Rightarrow N_{hit} \geq 4 \Rightarrow 8.4 \cdot 10^7$ ev.

1. Atmospheric muons: 'Shadow' of the shore in muons.

Standard track reconstruction

2. Atmospheric neutrinos:

9/3 + standard reconstruction + $z_{dist} > 35$ m

(z_{dist} - projection of the most distant channels on the track.

9 neutrino events

3. Nearly vertical upward muons.
(flux of muons from the center of the Earth)

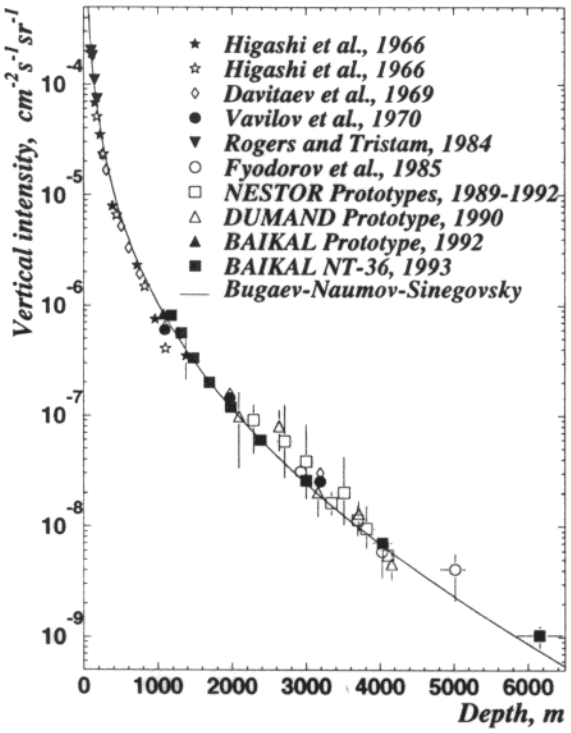
4 neutrino events.

4. Search for fast monopoles ($\beta \geq 0.8$).

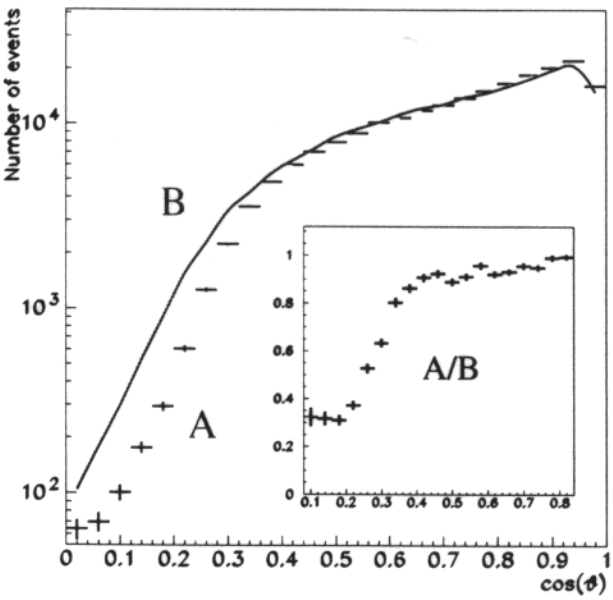
5. Showers from high energy neutrinos.

Downward Muons in Baikal

NT-36: Intensity versus Depth

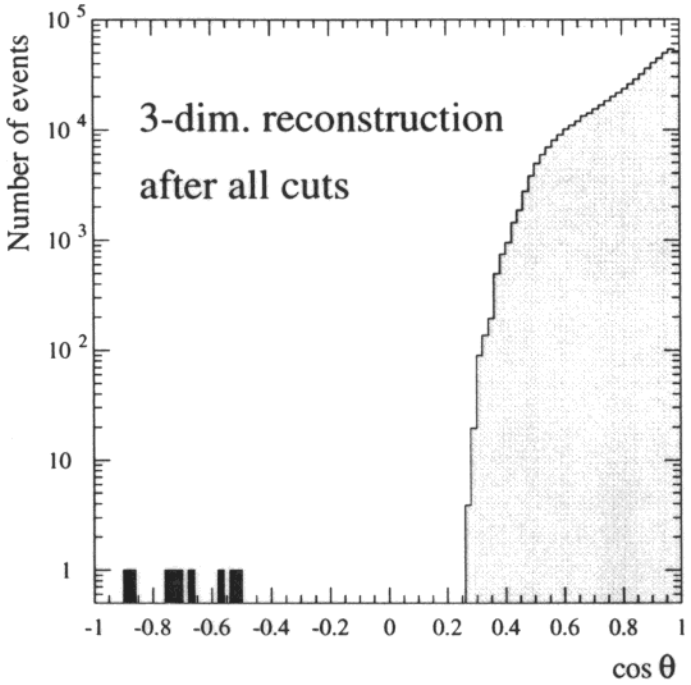


NT-96: Shadow of the Shore

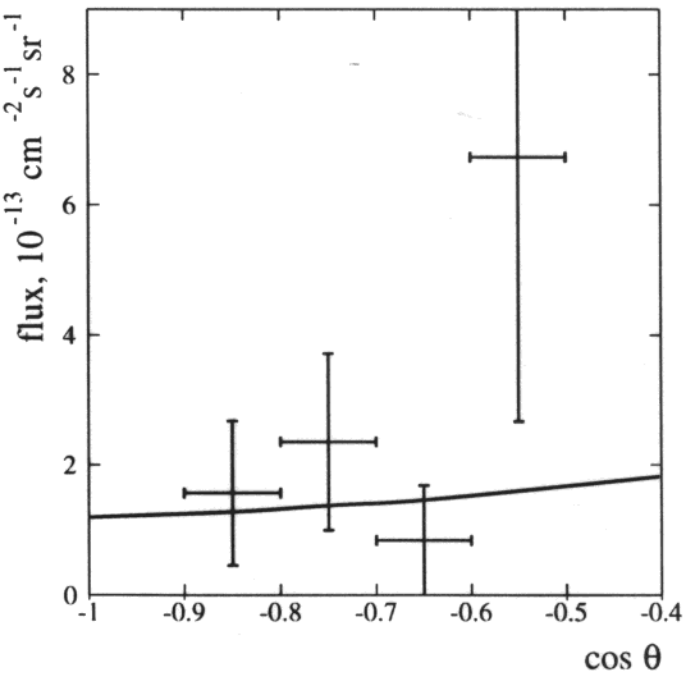


NT-96, 70 days

Angular distribution of events passing all cuts



Angular flux. In red: Atm.ν (Volkova)



Reconstruction and Cuts

1. Pre-Criteria
2. χ^2 Reconstruction

$$\chi_t^2 = \sum_{i=1}^{N_{hit}} (T_i(\theta, \phi, u_0, v_0, t_0) - t_i)^2 / \sigma_{ti}^2$$

3. Quality Criteria

- time-$\chi^2/NDF < 3.0$
- $P_{hit} \cdot P_{nohit} > 0.15$
- amplitude-$\chi^2/NDF < 2.0$
- amplitude correlation $A_{corr} > 0.1$

Search for nearly vertical upward muons

- Vertical upward speed: $|(t_i - t_j) - z_{ij}/c| < z_{ij}/dv + 2\delta$
- Minimum length:

  $L_{ev} = |i_{bot} - i_{top} + 1| > 8$
- Maximum amplitude (cascades):

  $A_{max} < 50$ photo-electrons
- COG (cascades below array):

  $COG_z = \sum_{i=1}^{N}(A_i \cdot z_i) / \sum_{i=1}^{N}(A_i) > 20\,\text{m}$
- Causality

  $t_{basic,i} = t_{bot} + \frac{t_{top} - t_{bot}}{z_{top} - z_{bot}} \cdot (z_i - z_{bot})$

  $\tilde{t} = \max(|t_i - t_{basic,i}|) < 60$ nsec
- Minimum "time length"

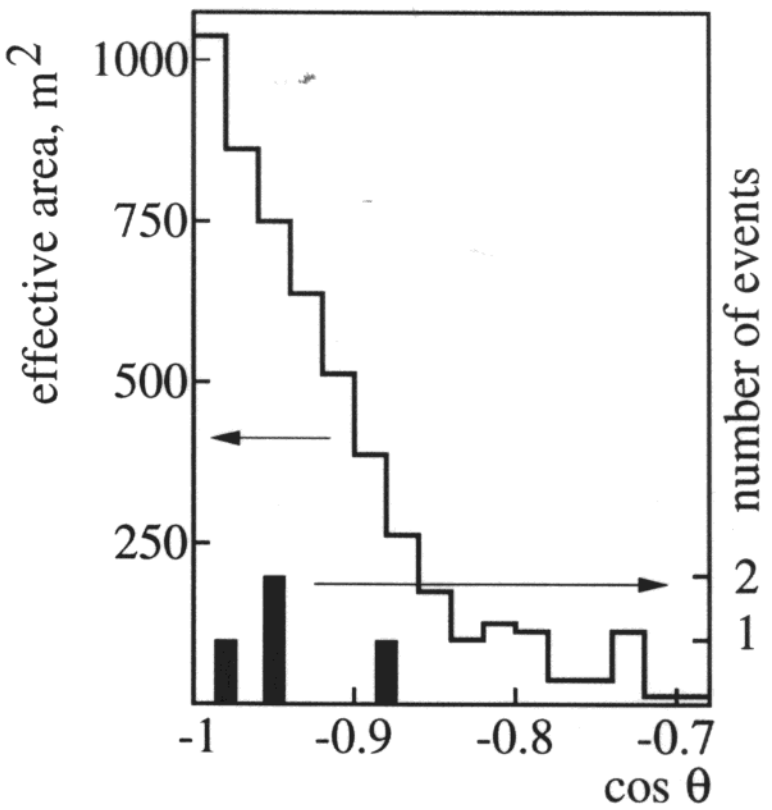
  $t_{tot} = \min(t_{top,i} - t_{bot,j}) > 150$ nsec

Results

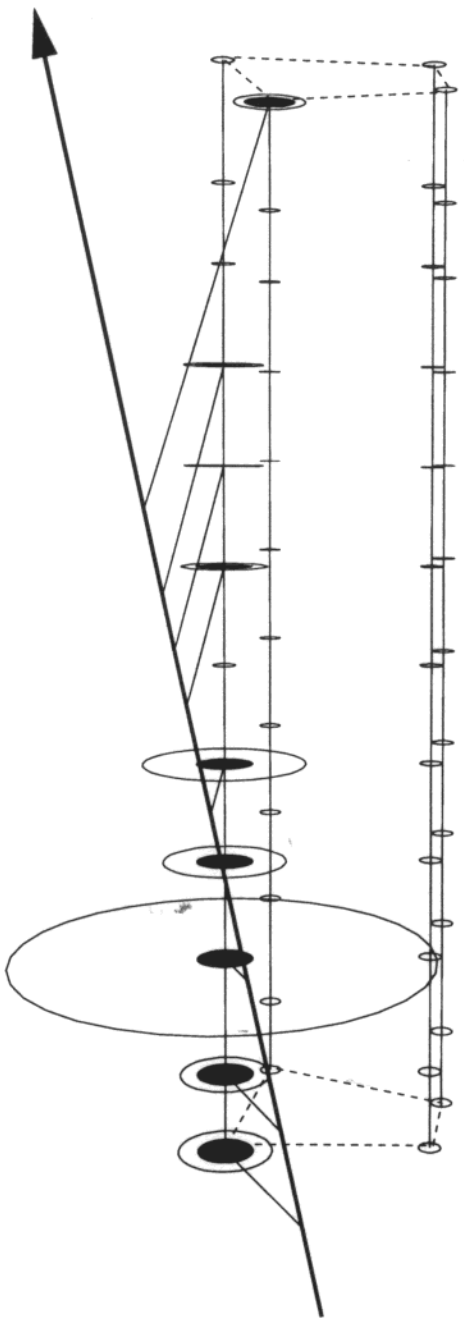
Expected number of atmospheric ν events and background events, and observed number of events after cuts (70 days NT-96).

after cut N^o $\rightarrow$	1	2	3	4	5	6
atm. ν, MC	11.2	5.5	4.9	4.1	4.8	3.5
background, MC	7106	56	41	16	1.1	0.2
experiment	8608	87	66	28	5	4

The effective area of *NT-96* after cuts *1-6* (histogram) compared to the reconstructed angles of the four events passing these cuts.



One Neutrino Candidate



The third event, with 9 hits at 2 strings and 162^o reconstructed zenith angle

Limits on muons from the center of the Earth

The number of events detected ("Data") and expected from atmospheric neutrinos ("Bg") for *NT-96*, as well as the 90% C.L. upper limits on the muon flux from the center of the Earth for four regions of zenith angles obtained *NT-96*, *Baksan*, MACRO and *Kamiokande*.

Zenith angles	Data	Bg	Flux limit ($10^{-14} \cdot \mathrm{cm}^{-2}\ \mathrm{sec}^{-1}$)			
			NT-96 10GeV	*Baksan* 1GeV	*MACRO* 1.5GeV	*Kam.* 3GeV
$\geq 150^\circ$	4	3.7	11.0	2.1	2.67	4.0
$\geq 155^\circ$	3	2.6	9.3	3.2	2.14	4.8
$\geq 160^\circ$	2	2.3	5.9	2.4	1.72	3.4
$\geq 165^\circ$	1	1.3	4.8	1.6	1.44	3.3

SEARCH FOR FAST MONOPOLES

1. P. Dirac

$$g = \frac{\hbar c}{2e} \approx 68.5$$

2. Acceleration in galactic magnetic fields.

$B \approx 2 \div 5\,\mu G$, $\ell \approx 300\,pc$; $\Delta E \approx 10^{11} \div 10^{12}\,GeV$

$M \lesssim 10^{11} \div 10^{12}\,GeV/c^2$ – fast monopoles

$$\Delta E_{Earth} \approx 10^{10}\,GeV$$

3. Trigger conditions

a) time cut for nearly vertical muons

b) $N_{hit} \geq 26$

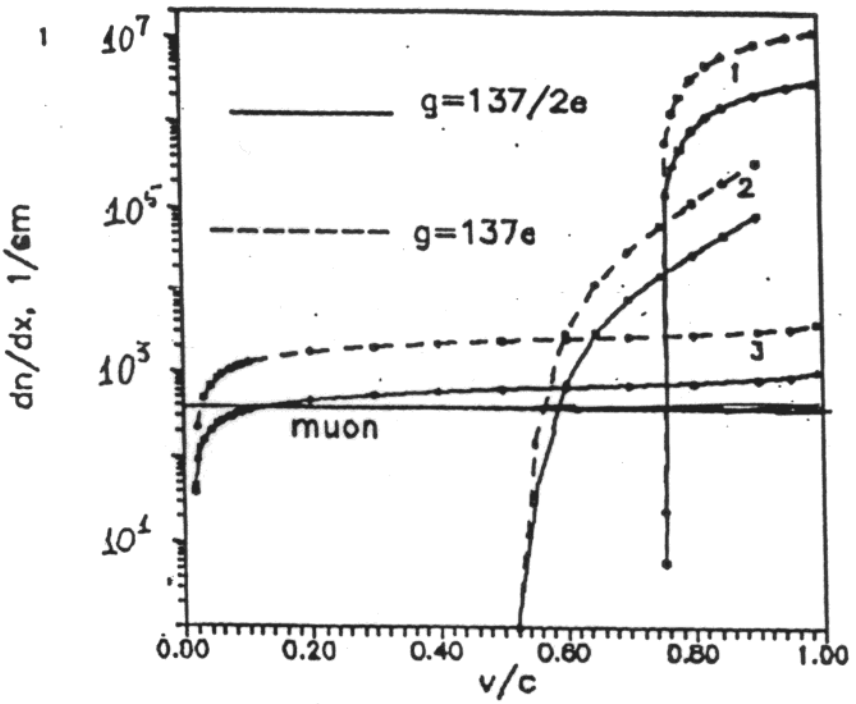
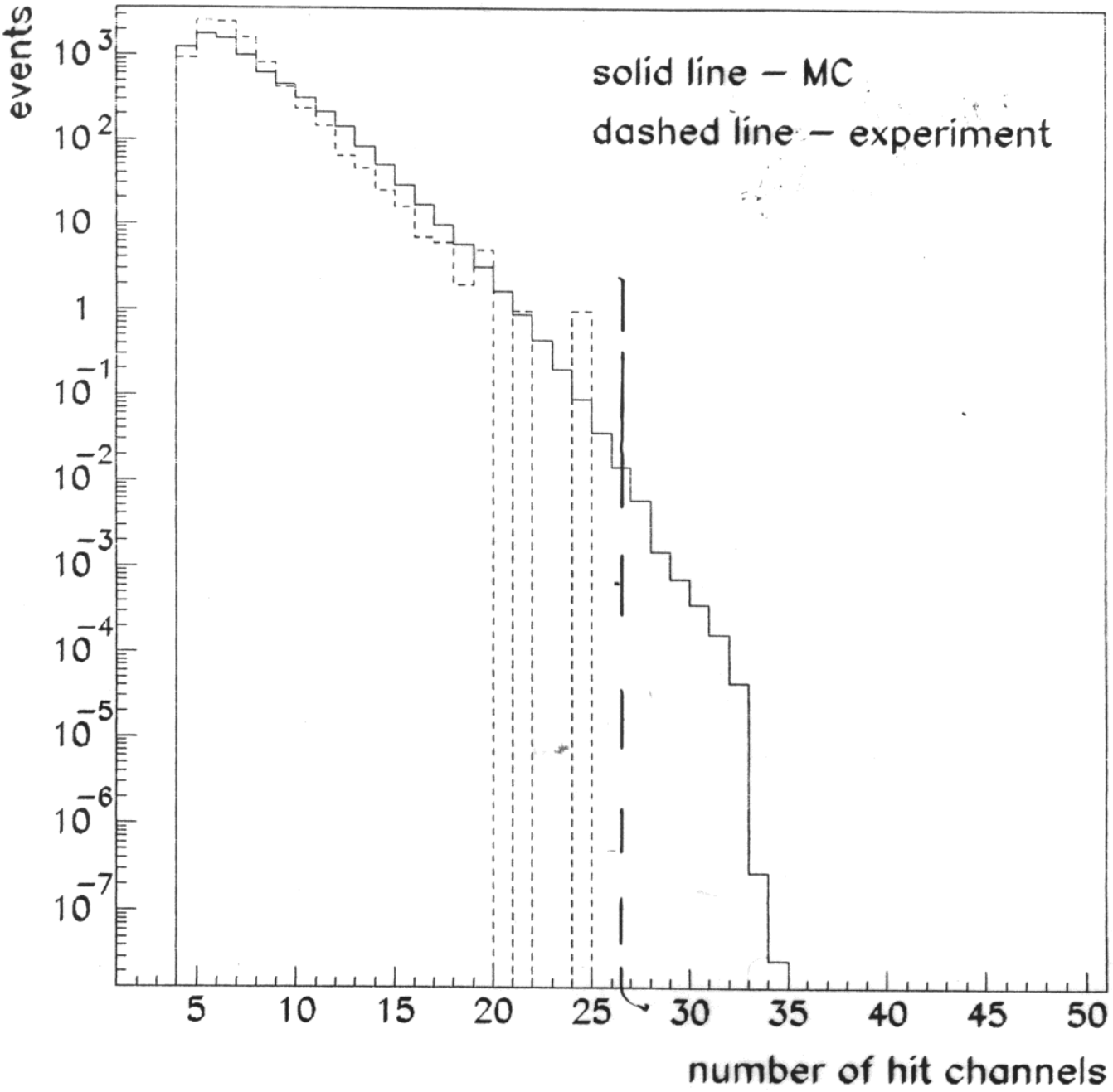
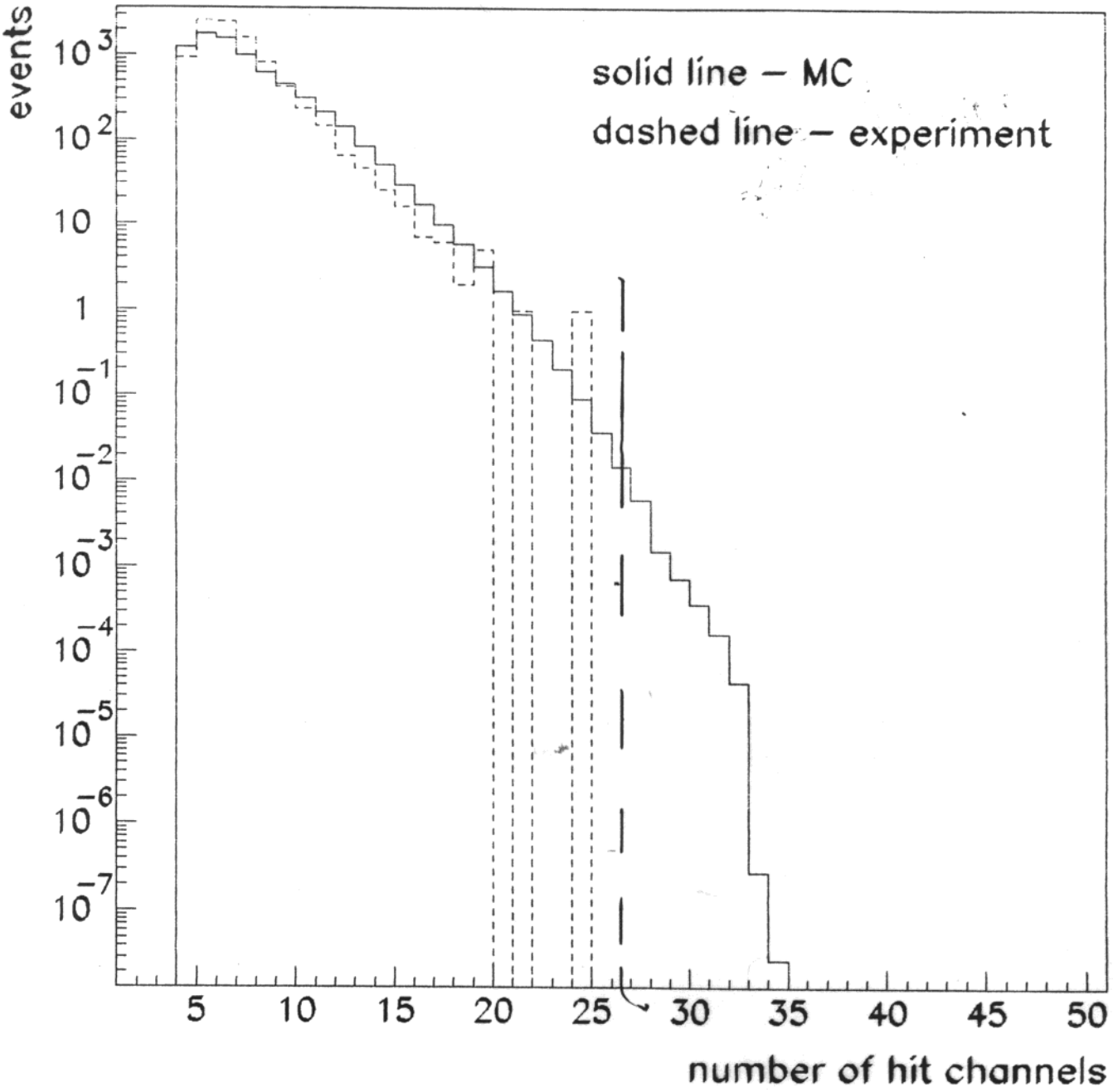


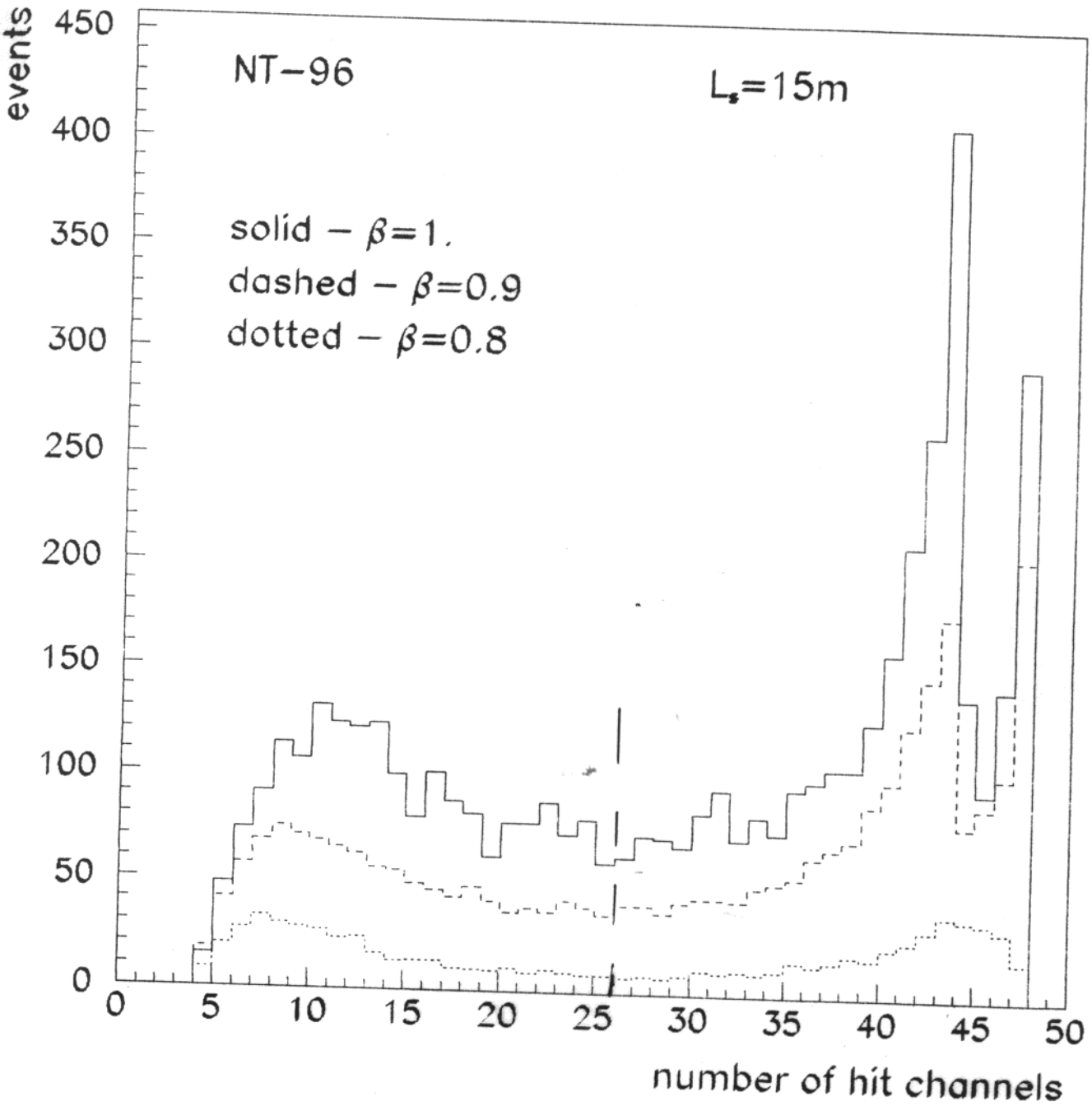
FIG.10. The rate of light output from monopole trajectory: 1—Cherenkov light of monopole itself; 2—Cherenkov light of the secondary —electrons; 3—luminescence.

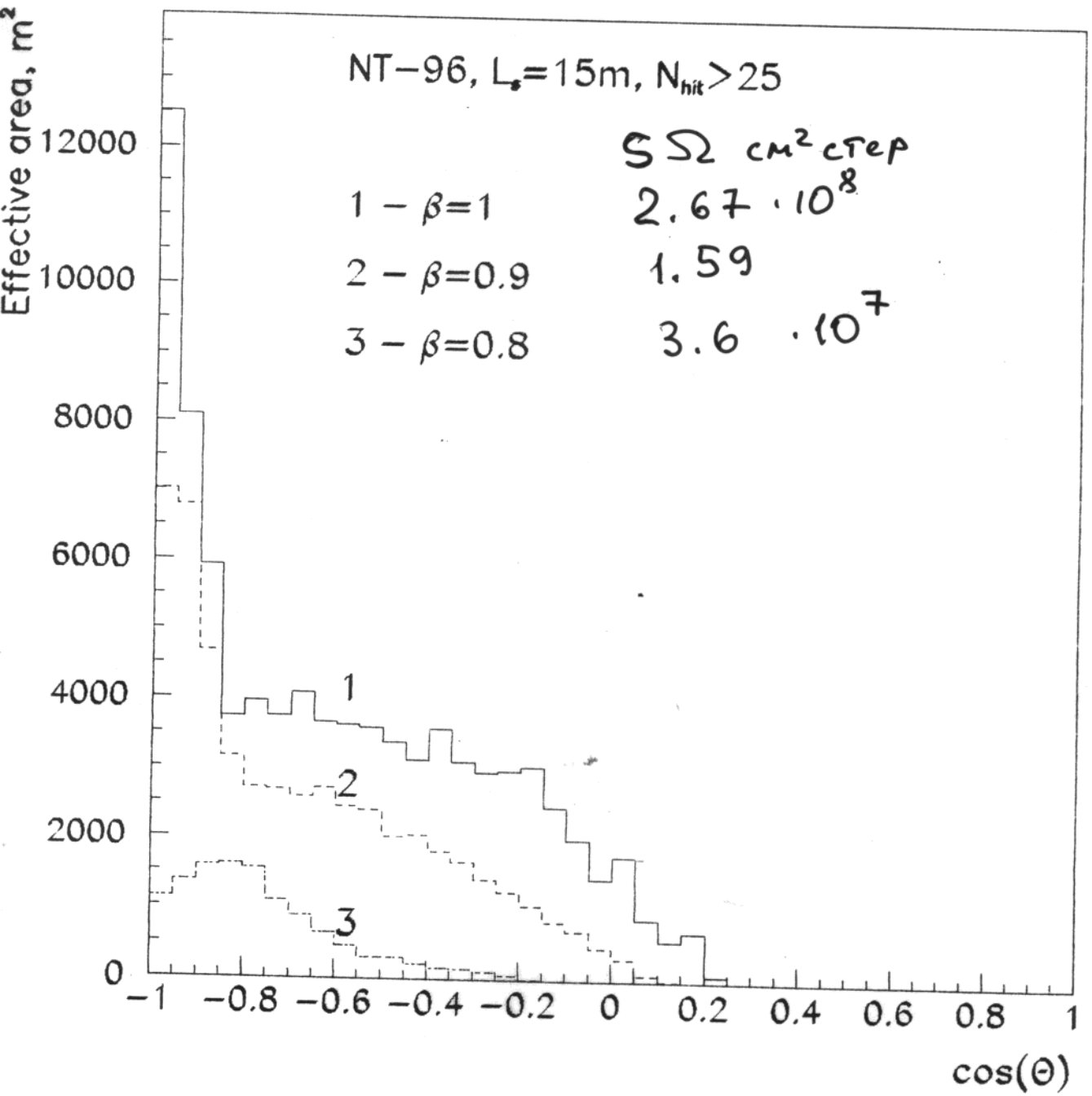


$$|(t_i - t_j) - \hat{z}_{ij}/c| < z_{ij}/dV + 2\delta$$



$$|(t_i - t_j) - \hat{z}_{ij}/c| < z_{ij}/dV + 2\delta$$


NT−96
L_s=15m
solid − β=1.
dashed − β=0.9
dotted − β=0.8
events
number of hit channels
0
50
100
150
200
250
300
350
400
450
0
5
10
15
20
25
30
35
40
45
50

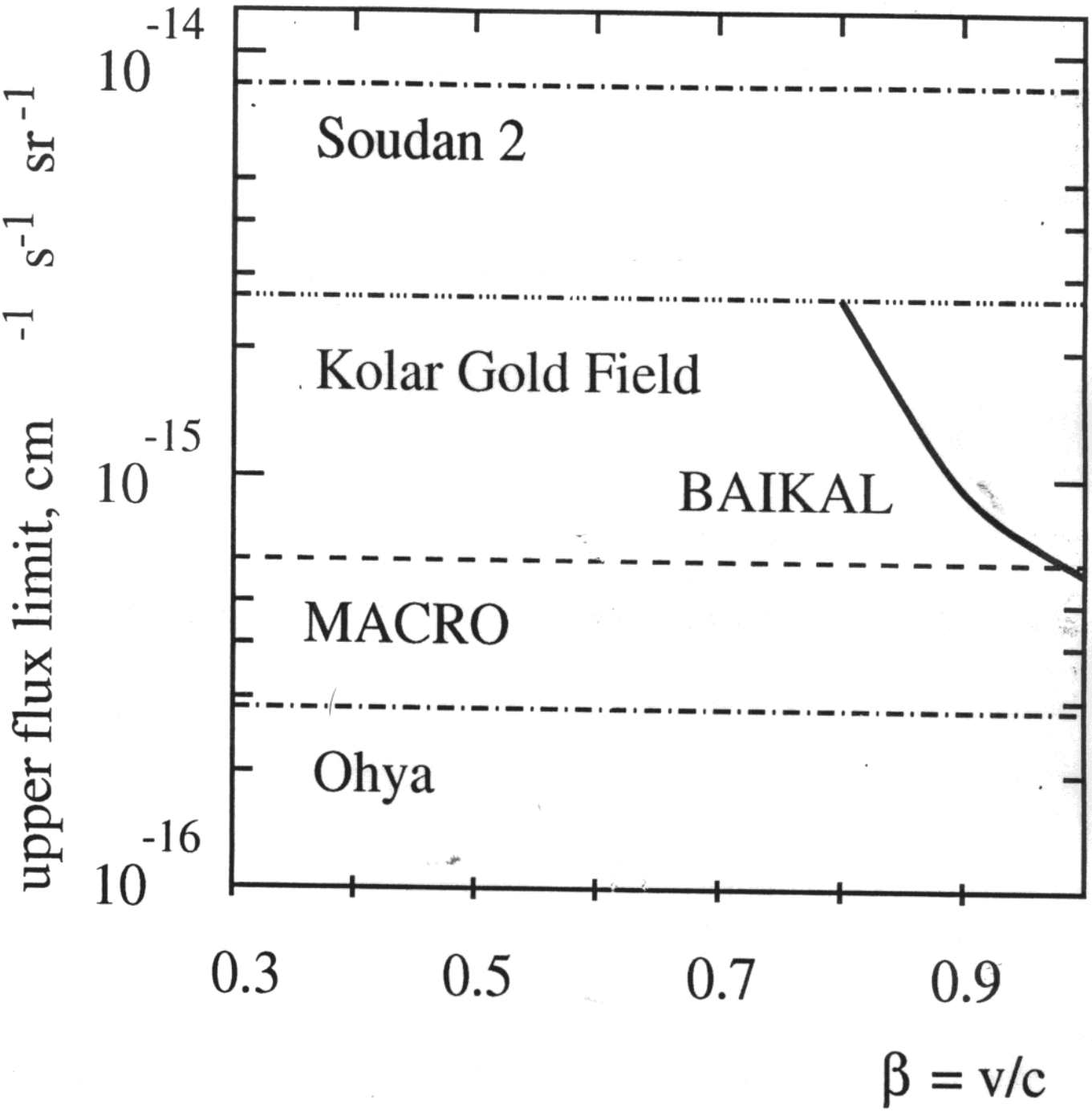


S Ω см² стер

2.67 · 10⁸

1.59

3.6 · 10⁷


upper flux limit, cm -1 s-1 sr-1
10-14
10-15
10-16
Soudan 2
Kolar Gold Field
BAIKAL
MACRO
Ohya
0.3
0.5
0.7
0.9
β = v/c

SEARCH FOR HIGH ENERGY NEUTRINO

SPS (DUMAND)

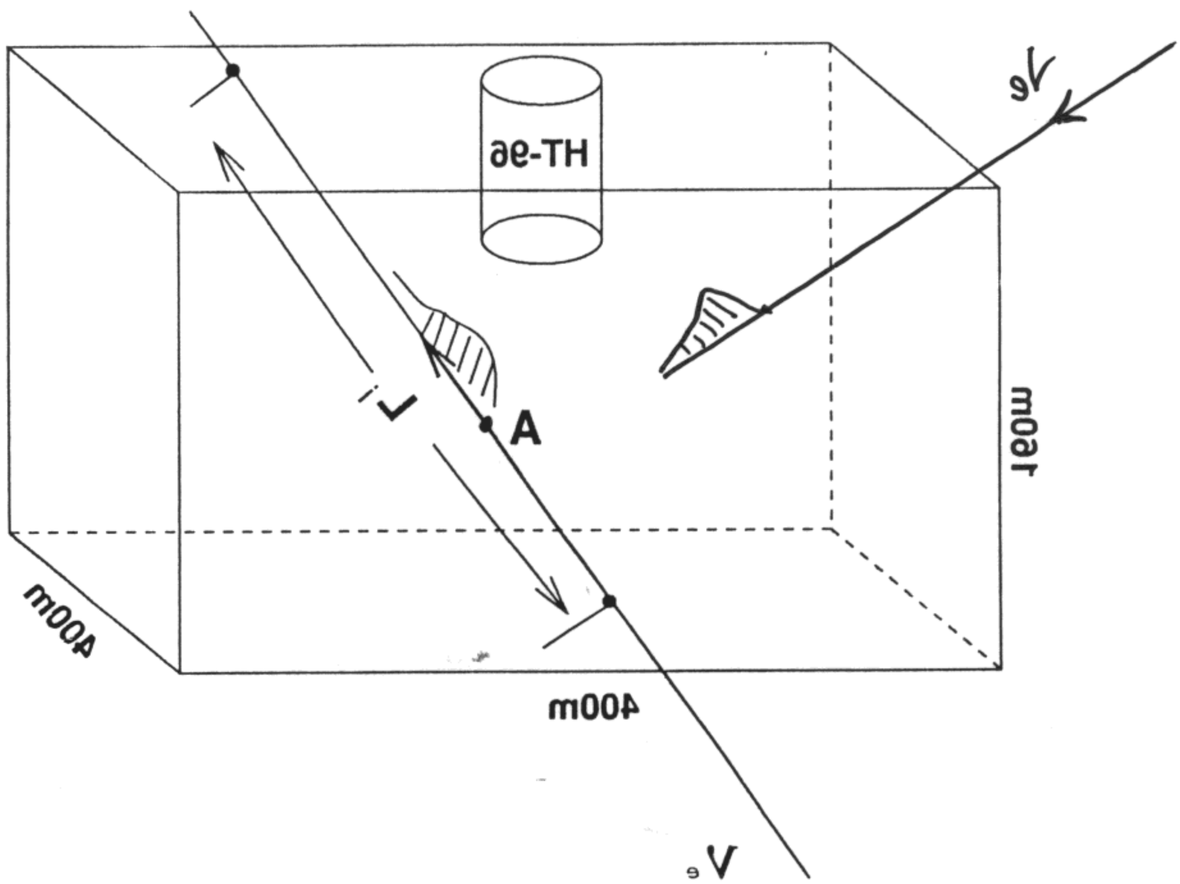
AMANDA-A

BAIKAL (PRELIMINARY).

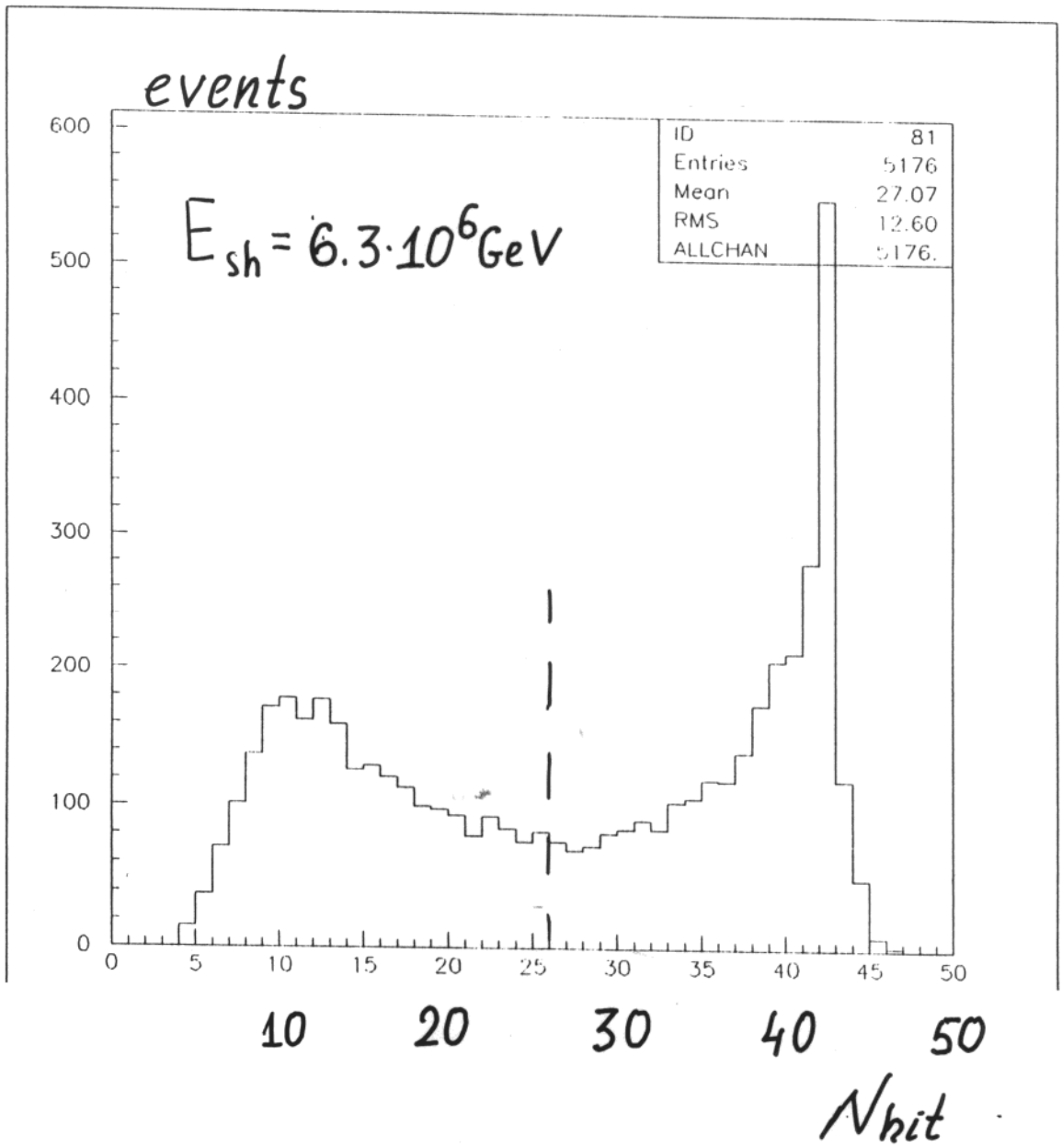
Trigger conditions:

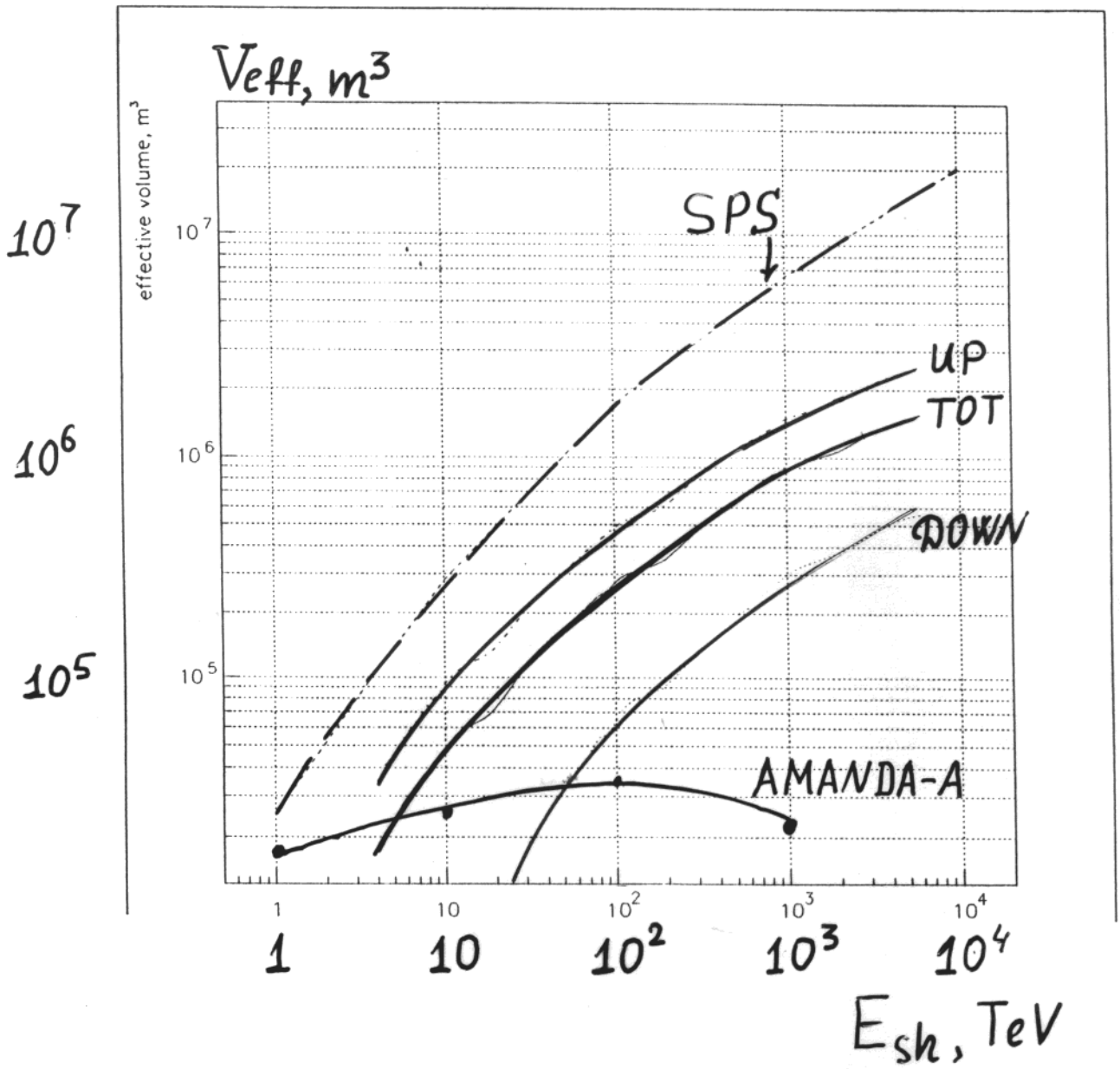
a) time cut for nearly vertical muons

b) $N_{hit} \geq 26$



HT-96
A
L
160m
400m
400m


events
$E_{sh} = 6.3 \cdot 10^6 GeV$
ID 81
Entries 5176
Mean 27.07
RMS 12.60
ALLCHAN 5176.
600
500
400
300
200
100
0
0 5 10 15 20 25 30 35 40 45 50
10 20 30 40 50
Nhit


Veff, m3
effective volume, m3
SPS
UP
TOT
DOWN
AMANDA-A
10^7
10^6
10^5
1
10
10^2
10^3
10^4
Esh, TeV

1. W - resonance

$\tilde{\nu}_e + e^- \rightarrow$ cascade

$$E_{res} = 6.3 \cdot 10^6 \text{ GeV}$$

$$\tilde{\sigma}(E_{res}) = 3.4 \cdot 10^{-31} \text{ cm}^2$$

$$\frac{(m_W - 2\Gamma_W)^2}{2m_e} < E < \frac{(m_W + 2\Gamma_W)^2}{2m_e}$$

$$\bar{\sigma} = 1.12 \cdot 10^{-31} \text{ cm}^2$$

$$\frac{dF}{dE} < \frac{2.3}{\frac{10}{18} N_A \bar{\sigma} T \bar{\Omega} V_{eff} \Delta E} = 3.7 \cdot 10^{-18} \text{ (cm}^{-2}\text{sec}^{-1}\text{st}^{-1}\text{ GeV}$$

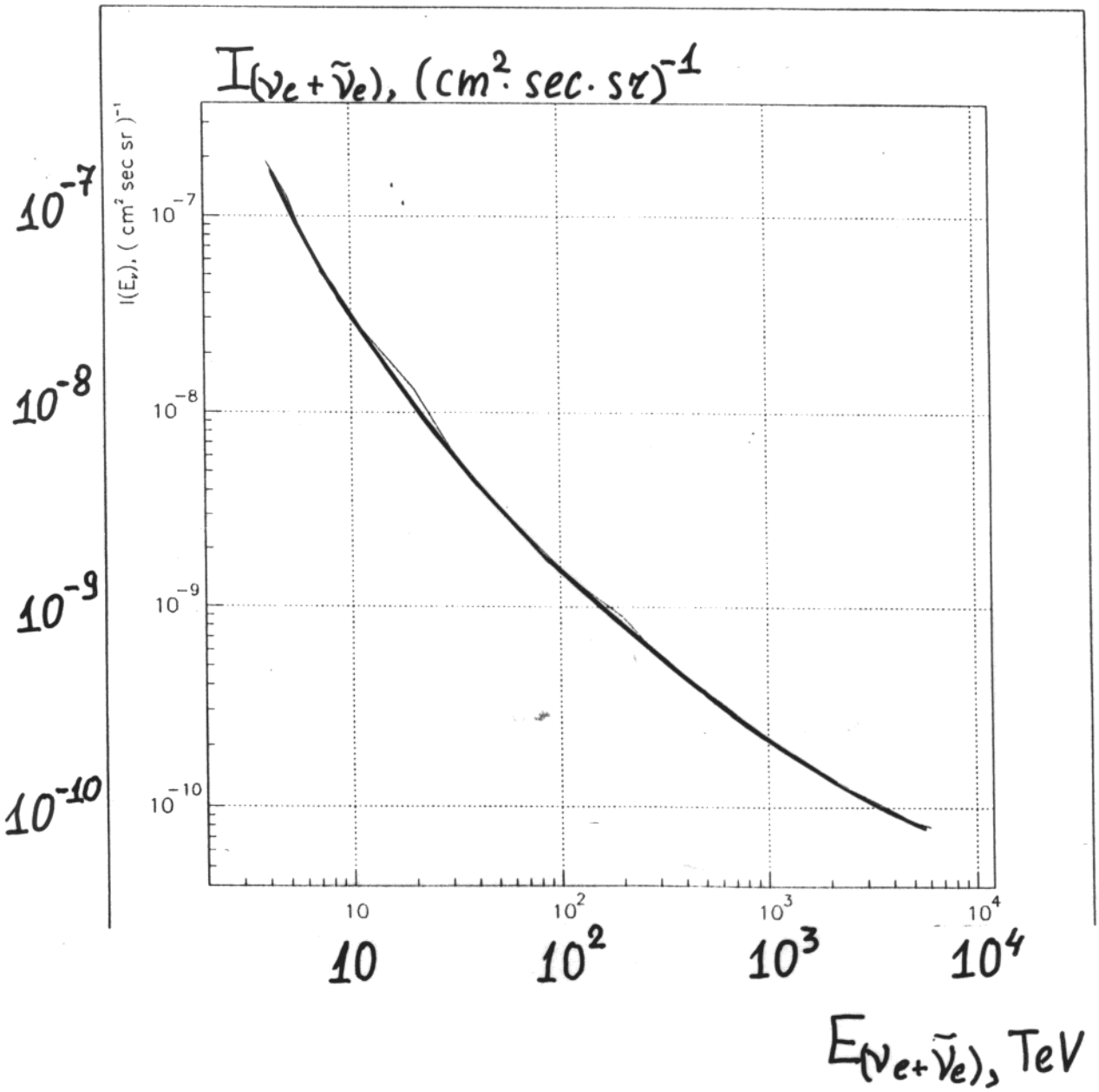
SPS = $1.1 \cdot 10^{-18}$ (— " —)

EAS-TOP = $7.6 \cdot 10^{-18}$ (— " —)

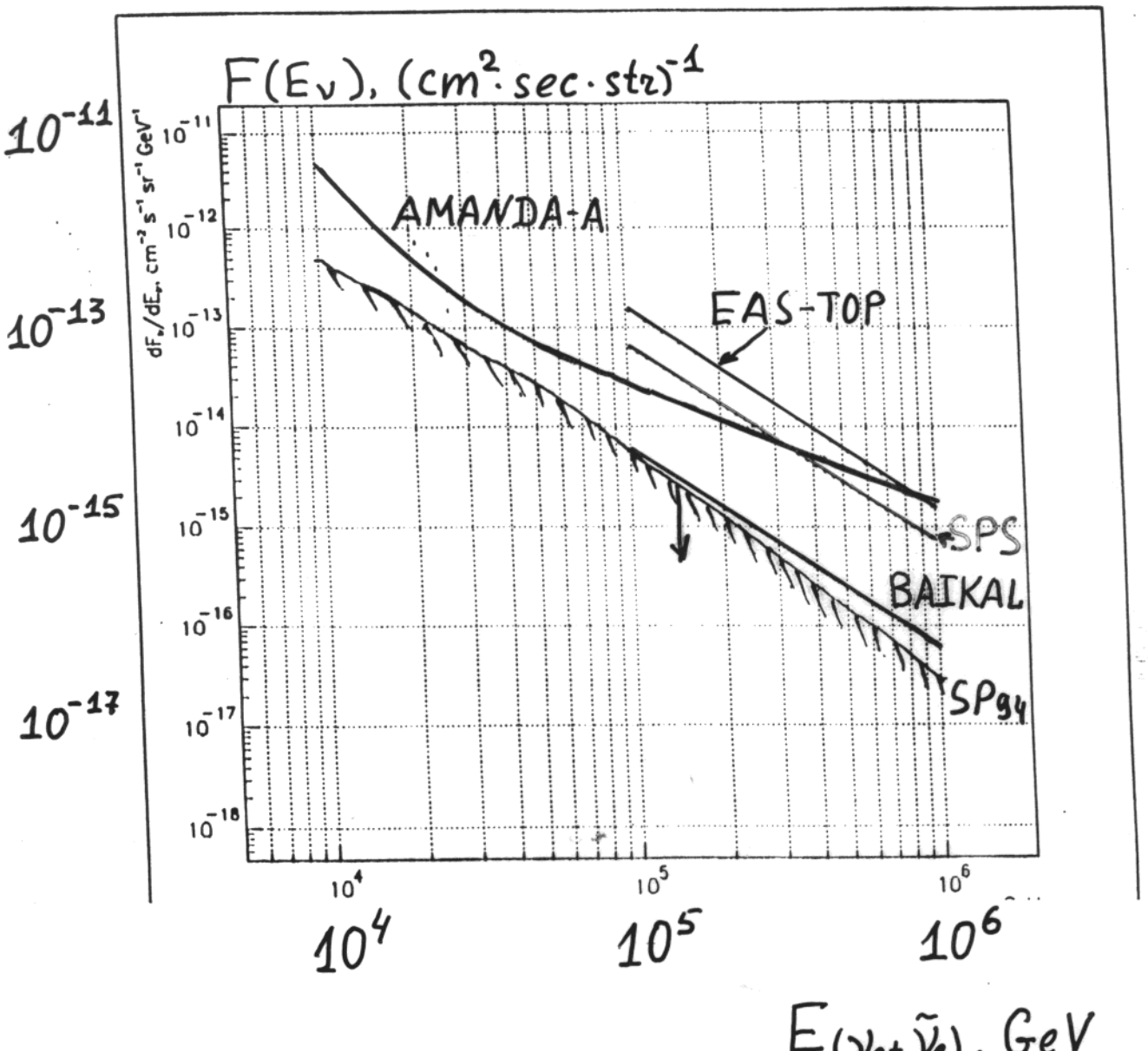
2. $\overset{(\sim)}{\nu}_e + N \xrightarrow{CC}$ cascade

$$10^{13} \lesssim E_\nu \lesssim 6 \cdot 10^{15} \text{ eV}.$$

$$I(E) = \int A\,\delta(E-E_0)\,dE_0 = \frac{2.3}{N_A\,\sigma\,T\,\pi\,V_{eff}}$$



$$\frac{dF(E_\nu)}{dE_\nu} = A\,\delta(E_\nu - E_0)$$


F(Eν), (cm²·sec·str)⁻¹
AMANDA-A
EAS-TOP
SPS
BAIKAL
SPASE
dF_ν/dE_ν, cm⁻² s⁻¹ sr⁻¹ GeV⁻¹
10⁻¹¹
10⁻¹³
10⁻¹⁵
10⁻¹⁷
10⁴
10⁵
10⁶
E(νe+ν̃e), GeV

$F_\nu \sim E^{-2}$