AMANDA

Status, Results, Future

CHRISTIAN SPIERING

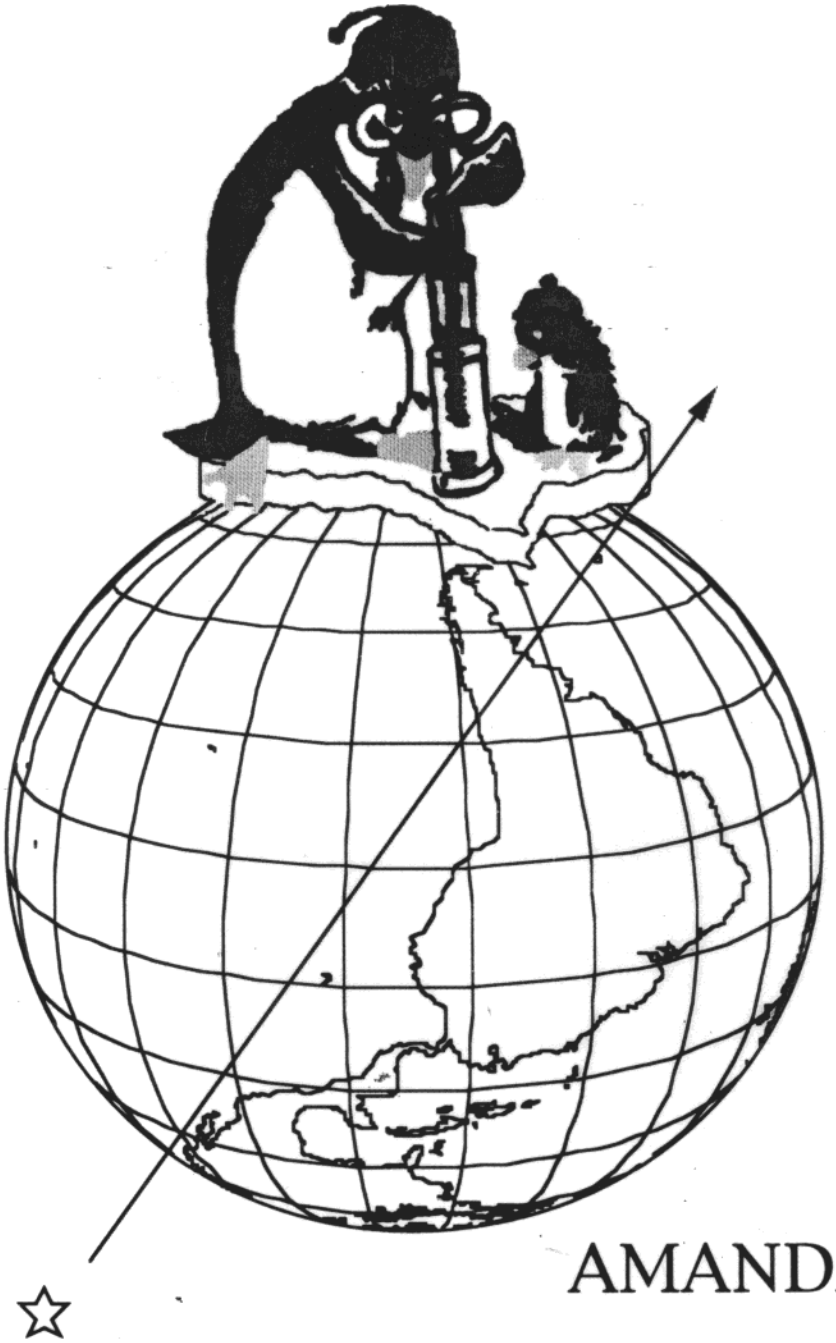
DESY Zeuthen

Venice, Feb.25, 1999

AMANDA

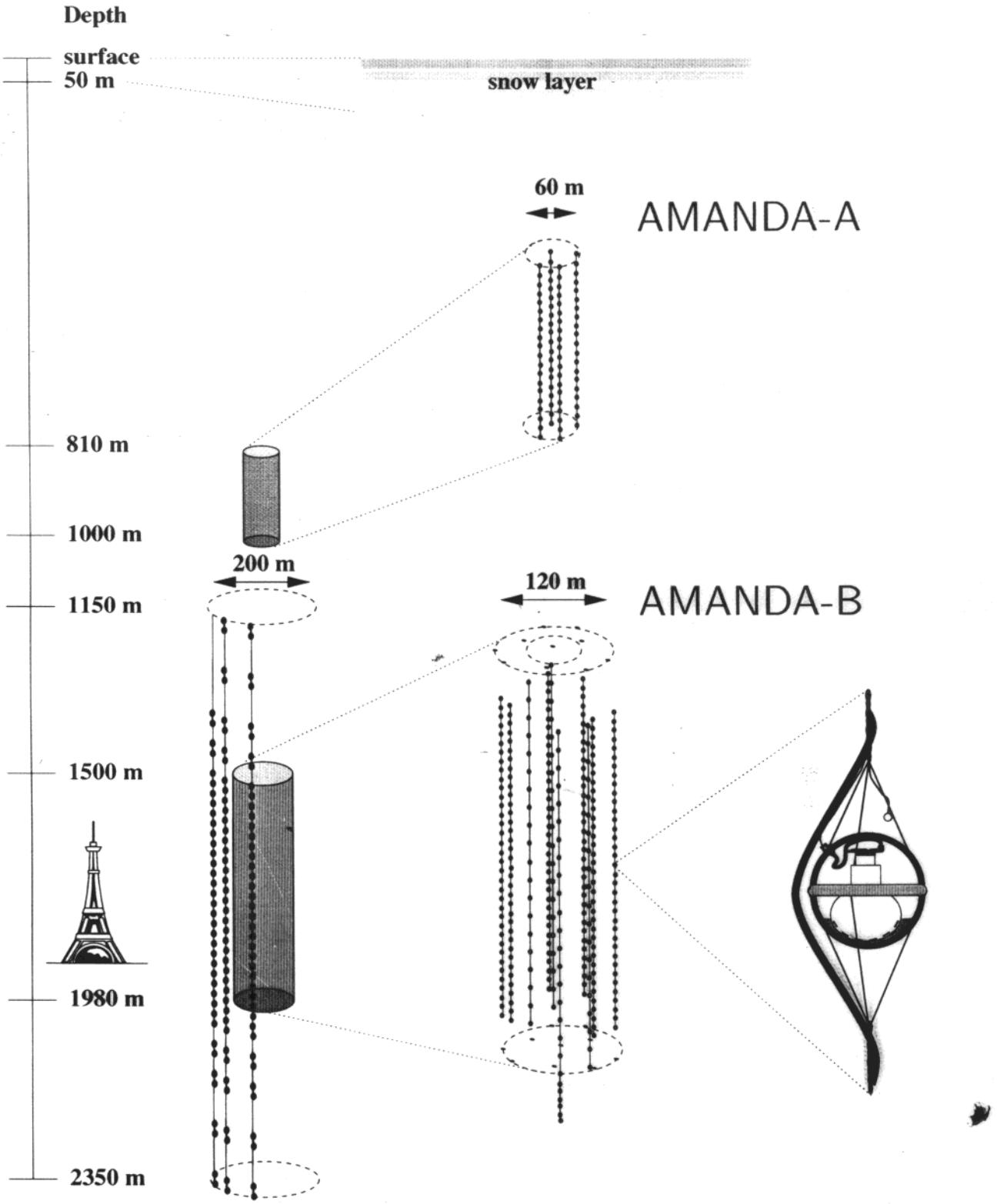
Antarctic Muon And Neutrino Detector Array

- Lawrence Berkeley National Laboratory, Berkeley (USA)
- University of California, Berkeley (USA)
- University of Brussels, Brussels (Belgium)
- University Kansas, Lawrence (USA)
- Bartol Research Institute, Newark (USA)
- University of California, Irvine (USA)
- University of Kalmar, Kalmar (Sweden)
- University of Wisconsin, Madison (USA)
- University of Pennsylvania, Philadelphia (USA)
- University of Stockholm, Stockholm (Sweden)
- University of Uppsala, Uppsala (Sweden)
- DESY-Zeuthen, Zeuthen (Germany)



AMANDA

The AMANDA Experiment



AMANDA as of 1998
Eiffel Tower as comparison
(true scaling)

zoomed in on
AMANDA-A (top)
AMANDA-B10 (bottom)

zoomed in on one
optical module (OM)

- Configuration
- Drilling, Geometry
- Ice
- Calibration with Surface Arrays

- B4
  - Depth-Intensity
  - Neutrino Separation

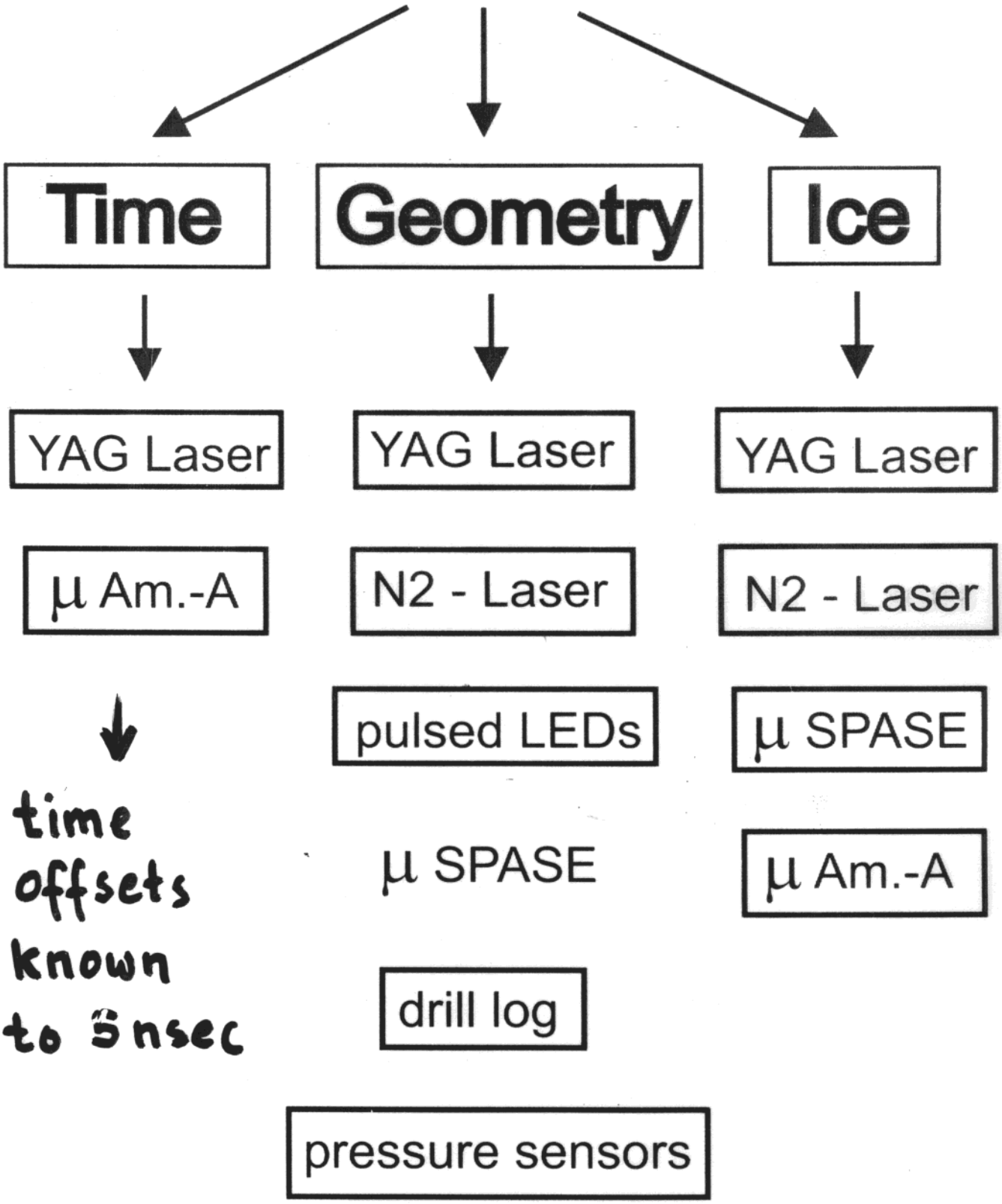
- B10
  - Neutrinos
  - Search for GRB Coincidences
  - Search for Magnetic Monopoles

- Amanda-II

- DeepIce

- IceCube

Calibration Procedures



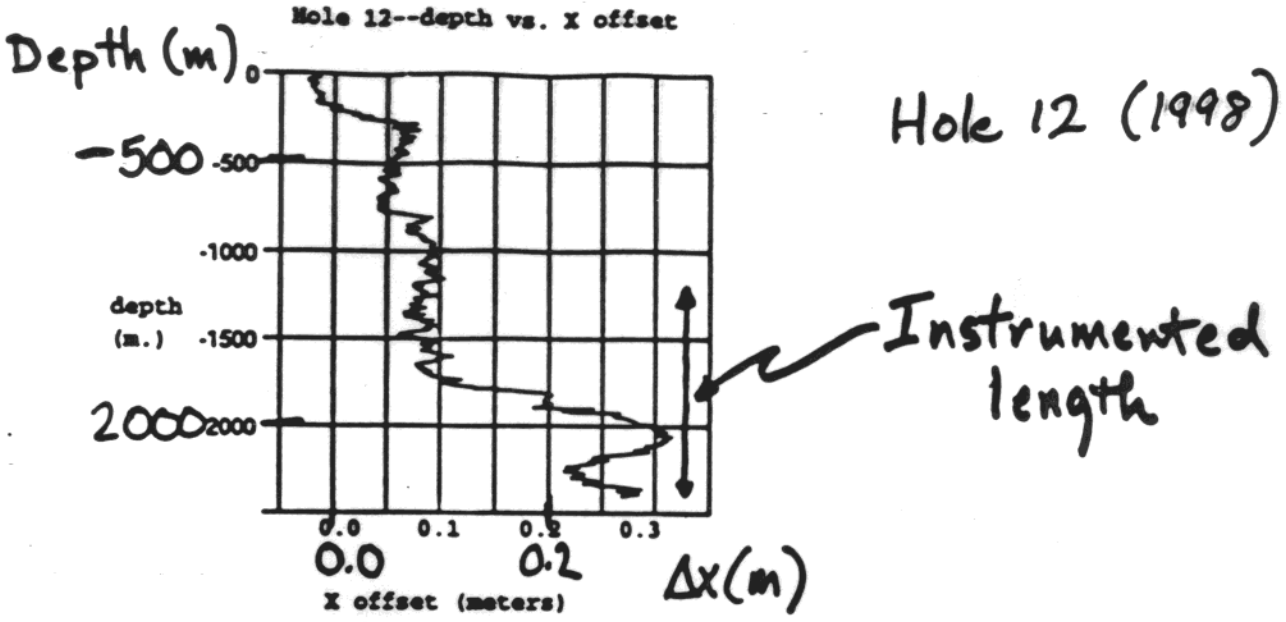


Figure 9

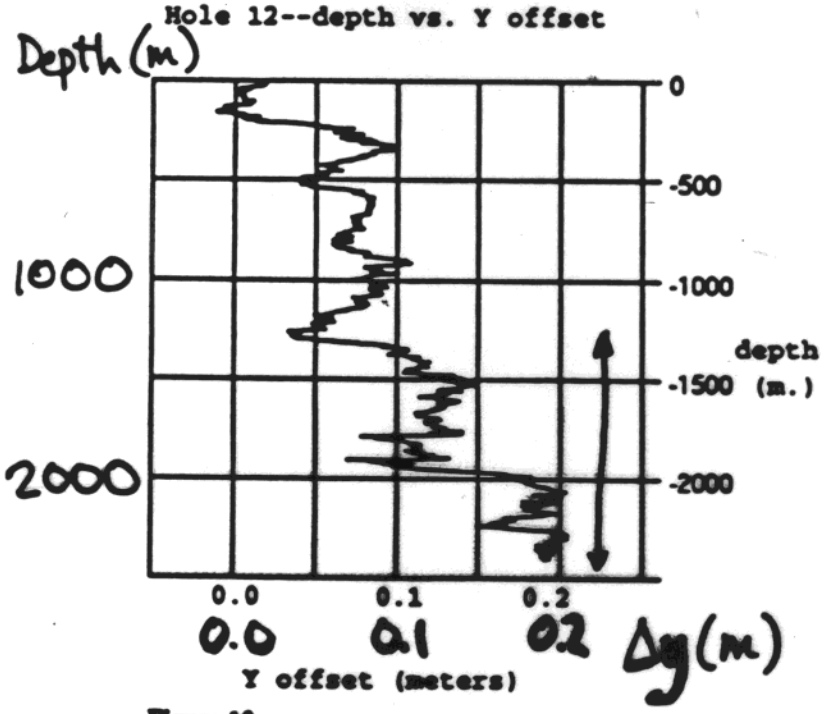
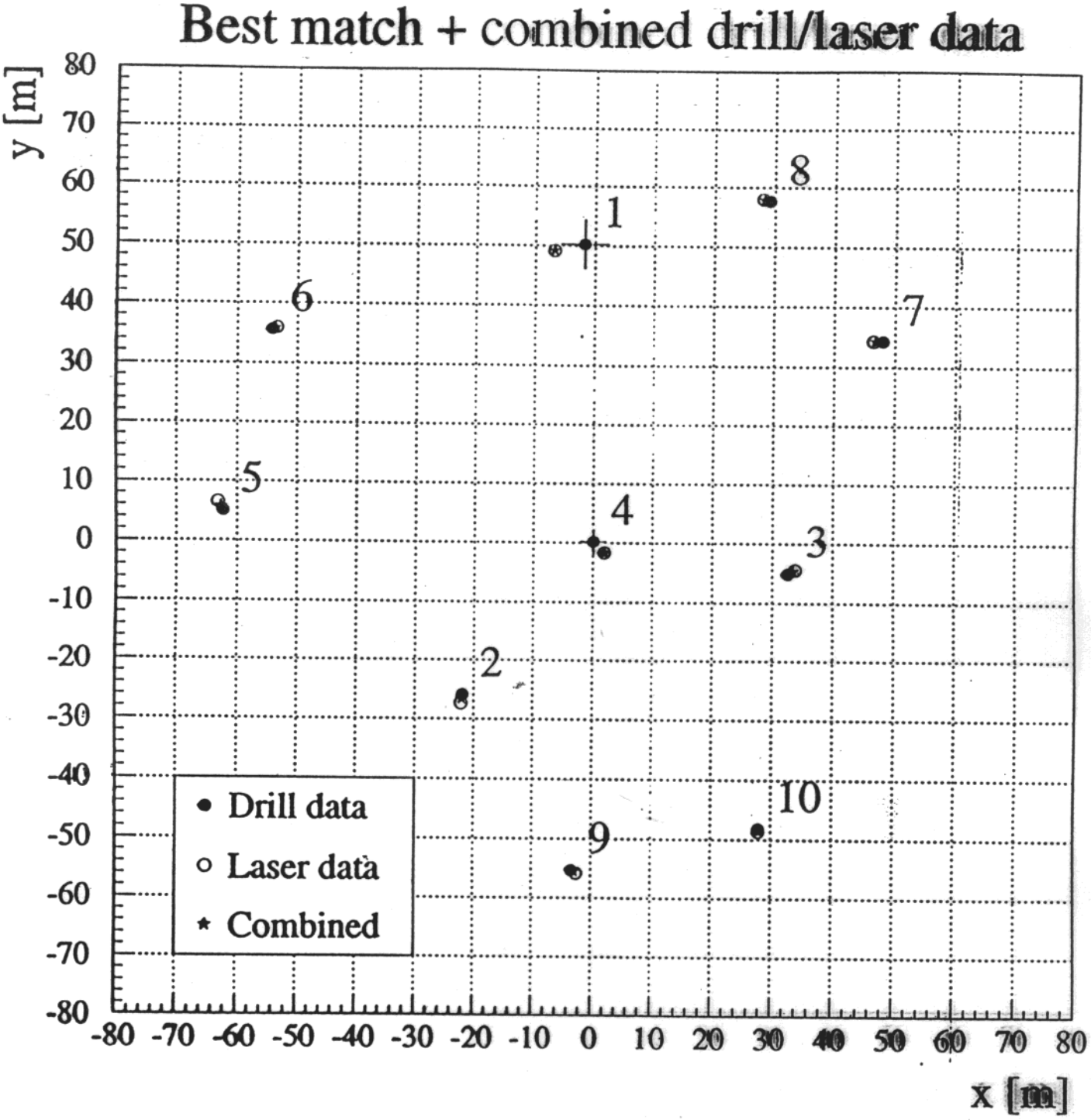


Figure 10

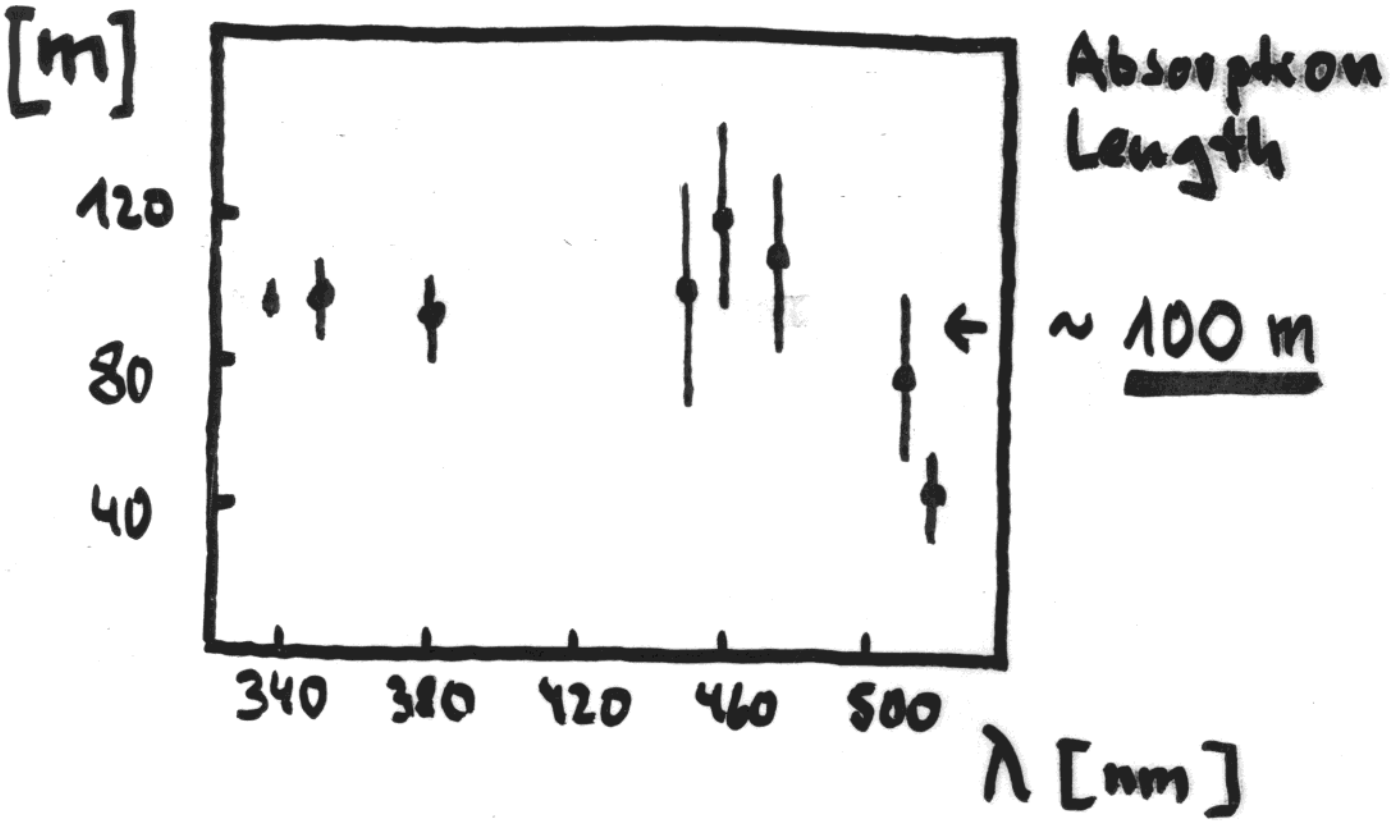
Geometry



Combined accuracy: X ,Y, relative Z ≈ 0.5 m

absolute Z 1-2 m

Ice properties from B4

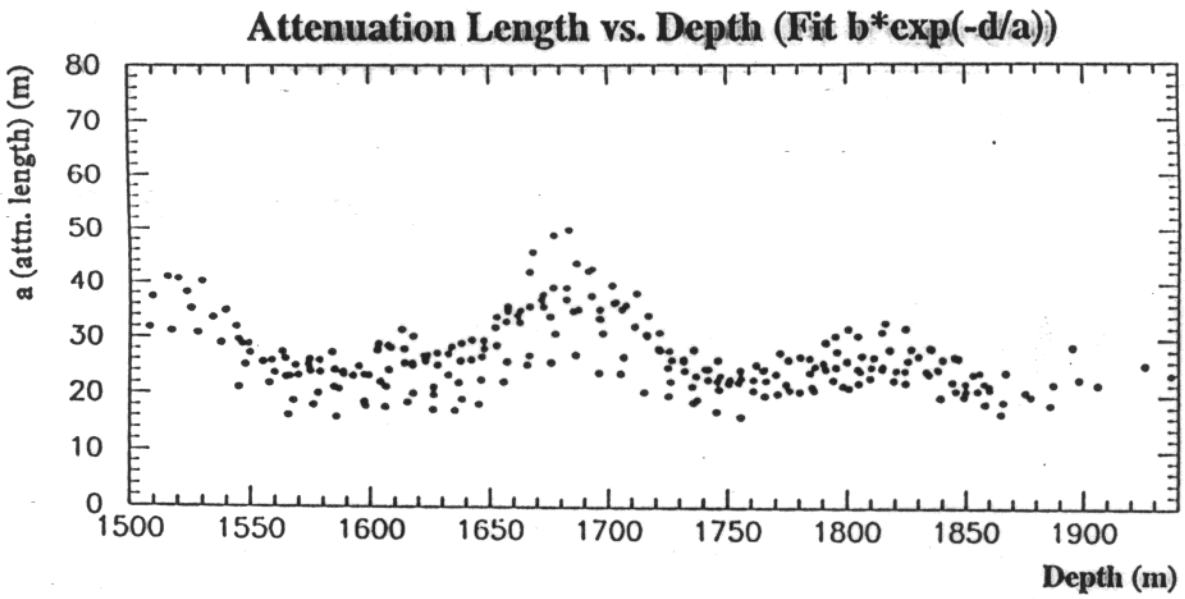


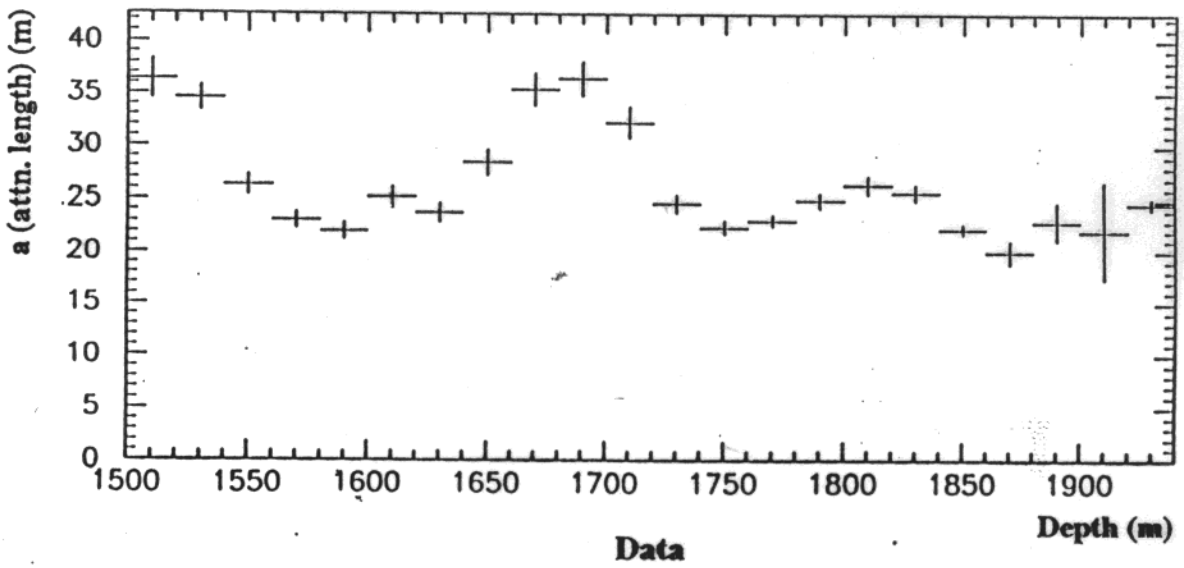
effective scattering length

$$\lambda_{eff} = \frac{\lambda_{sc}}{1 - \langle \cos\theta \rangle} \approx \underline{24\,m}$$

→ attenuation length ~ 27 m

λ_{att} versus depth:

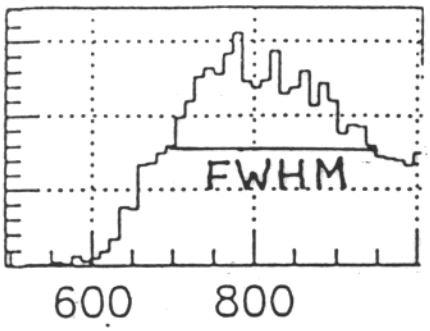




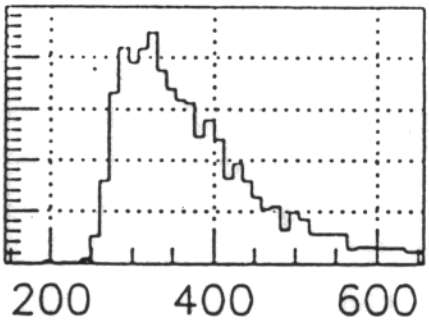
→ ⟨Attenuation length⟩ = 27 m
variations ± 25 %

consistent with ⟨absorption length⟩ = 24 m
⟨eff. scattering length⟩ = 96 m

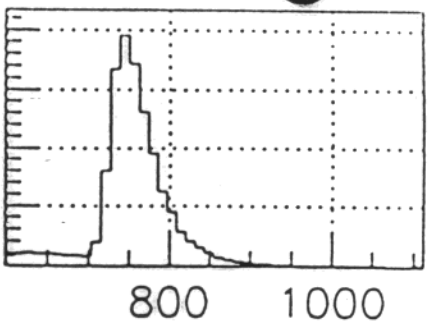
Arrival time distributions for 532 nm pulses between strings 12 & 13 (30 m)



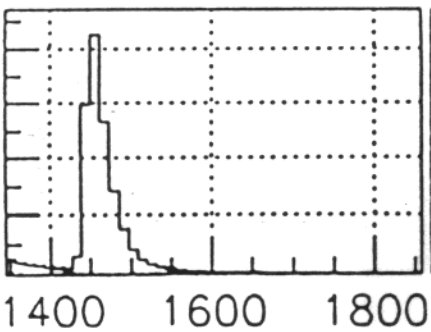
d = 1145 m



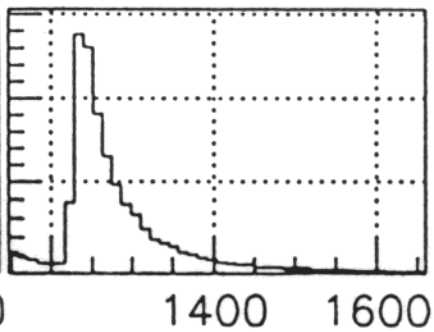
1245 m



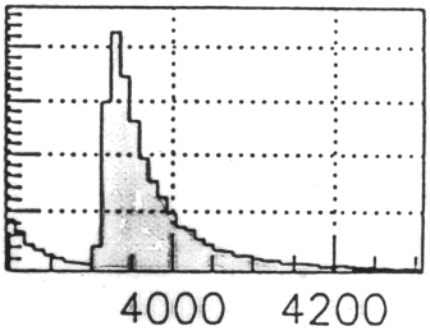
1305 m



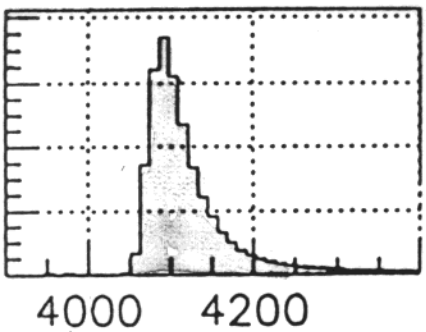
1385 m



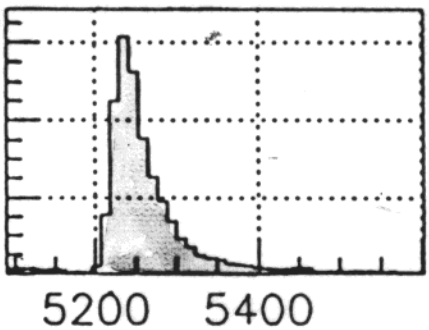
1465 m



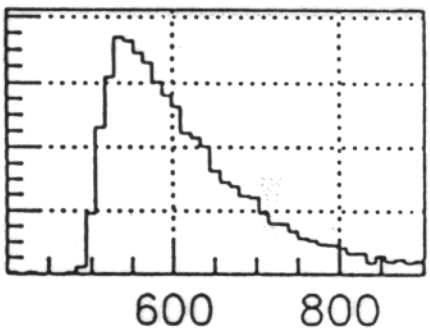
1605 m



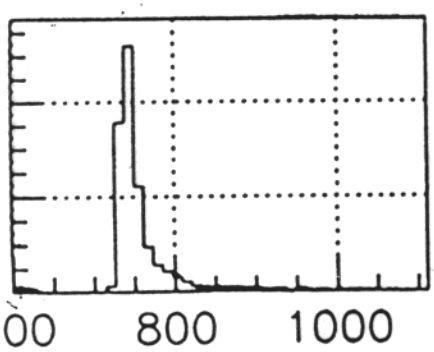
1765 m



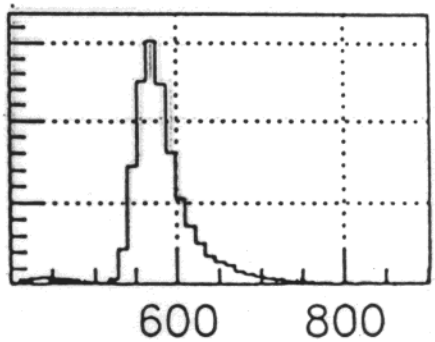
1905 m



2025 m

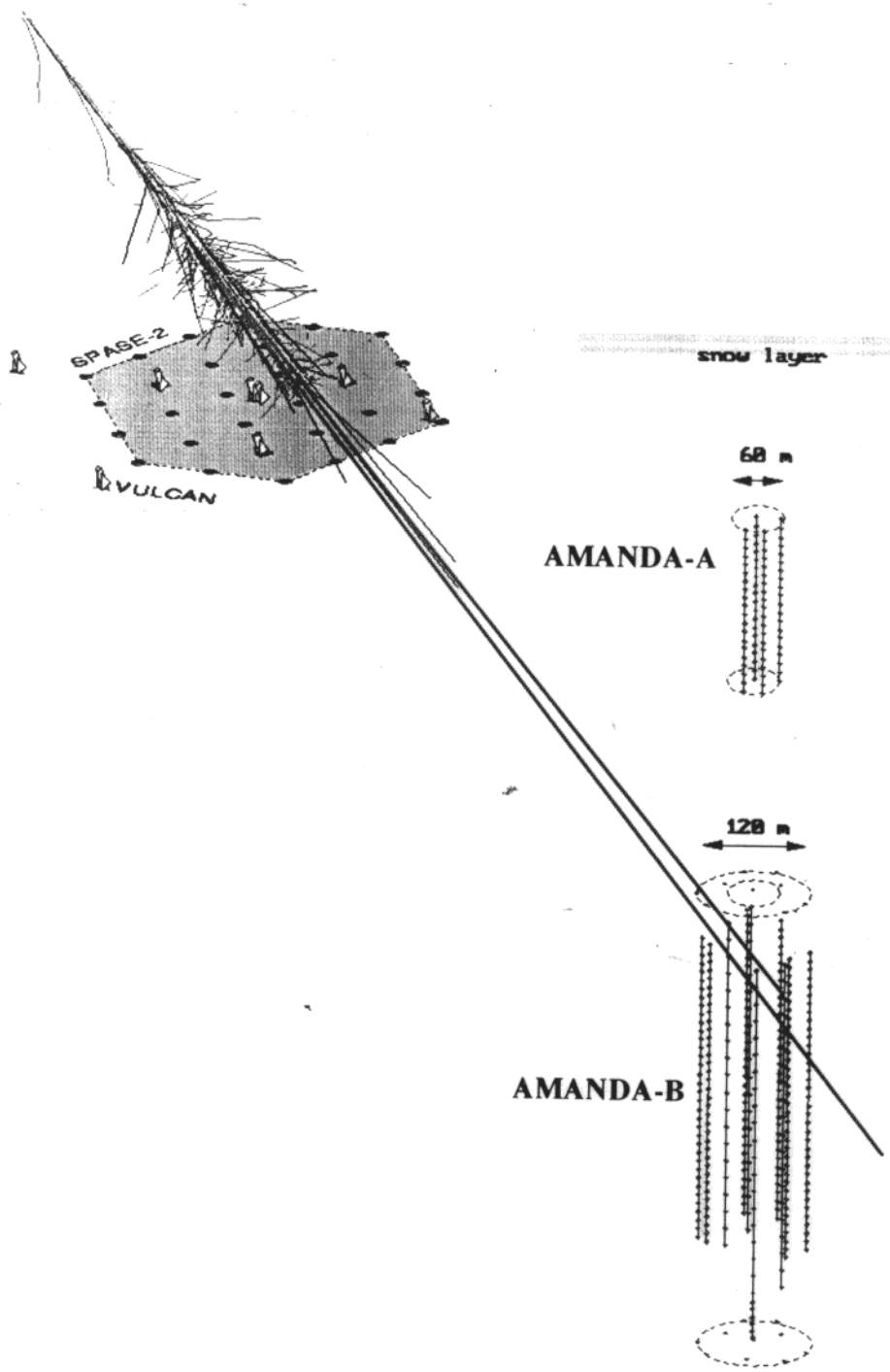


2125 m

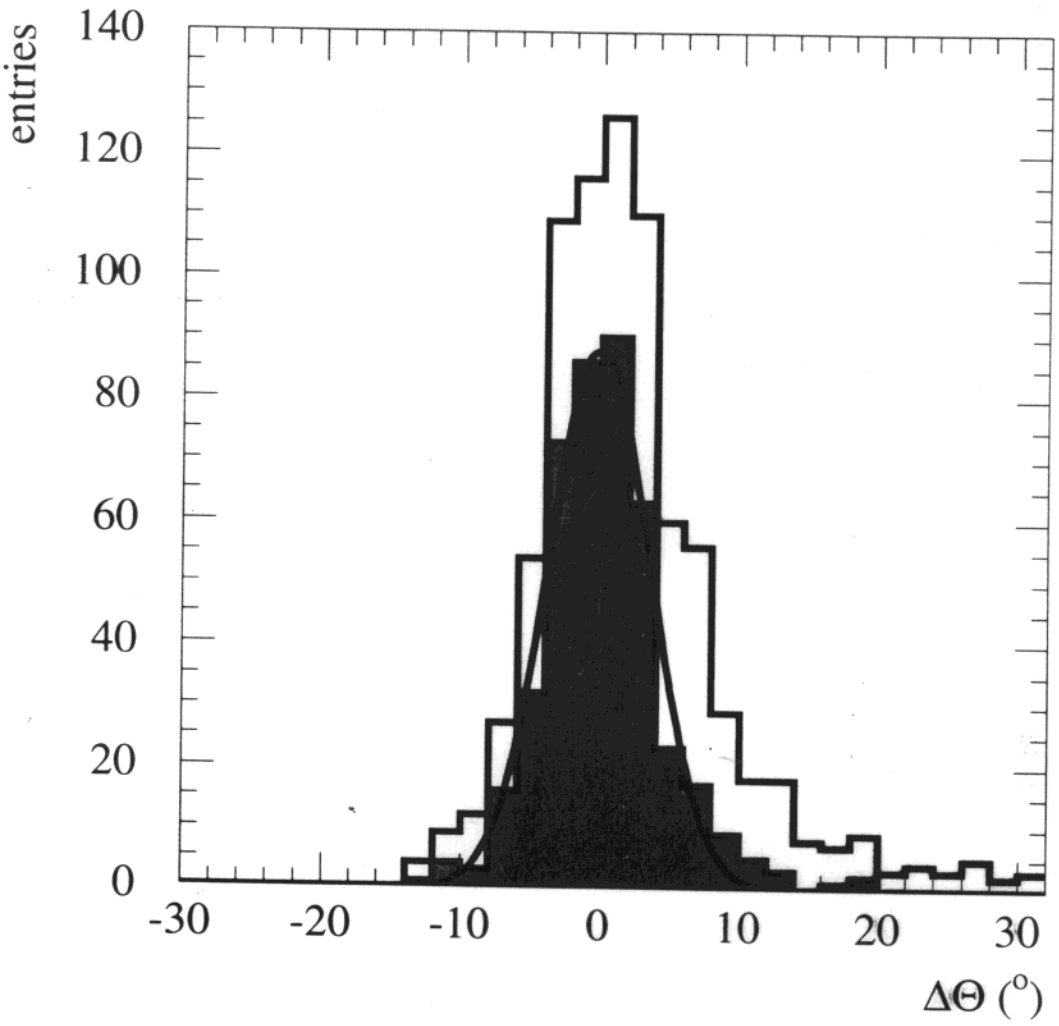


2285 m

SPASE-II AMANDA Coincidences



SPASE-II AMANDA-B 4 coincidences
Reconstructed zenith difference



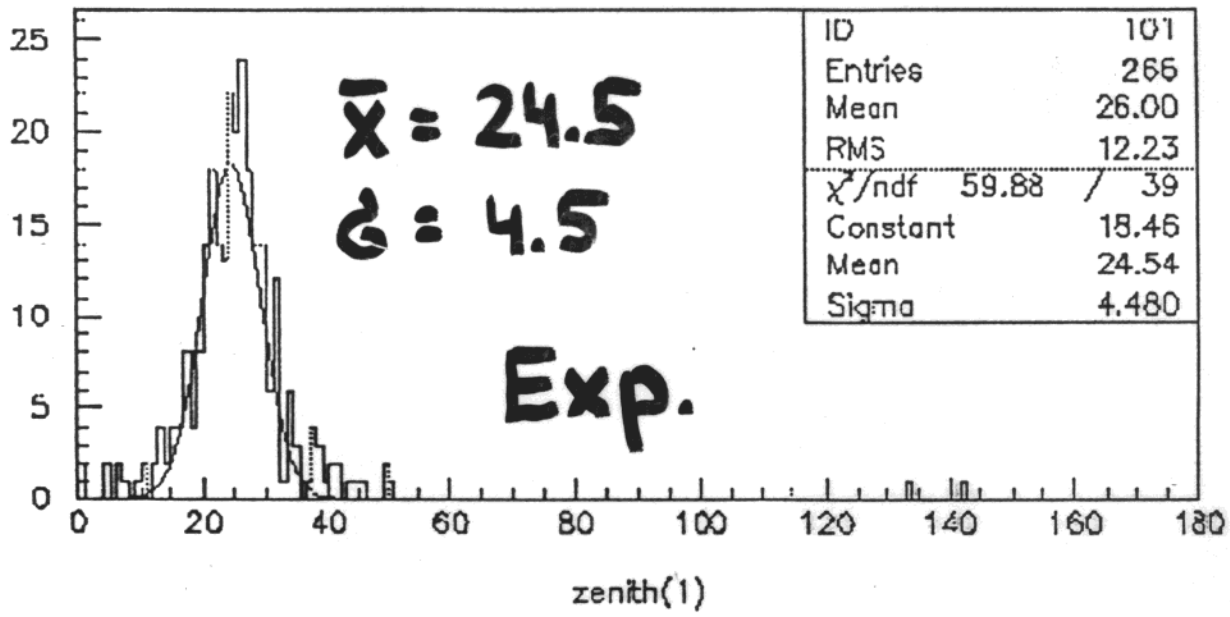
After Cuts

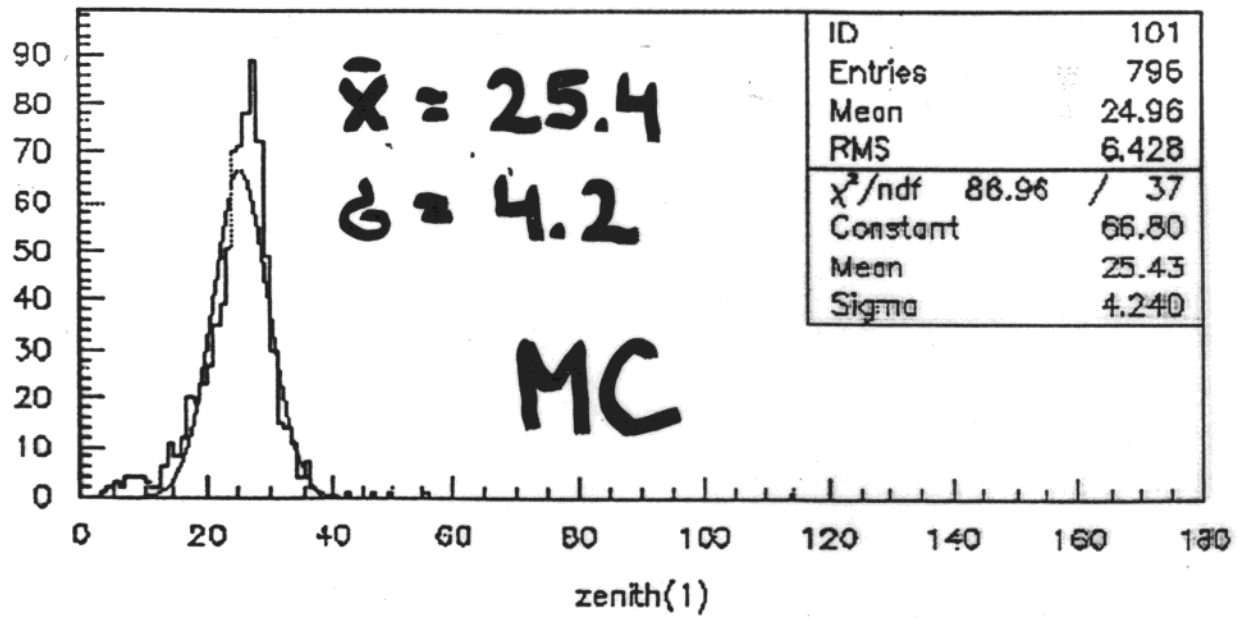
Gaussfit: Mean $= -0.15°$ Sigma $= 3.6°$

Coincidences GASP – AMANDA B10

Zenith GASP –- Am - B ≈ 27°, GASP resolution 1°

Reconstructed zenith of coincident events:





Amanda-B4

- Depth Intensity Relation
- Neutrino Separation

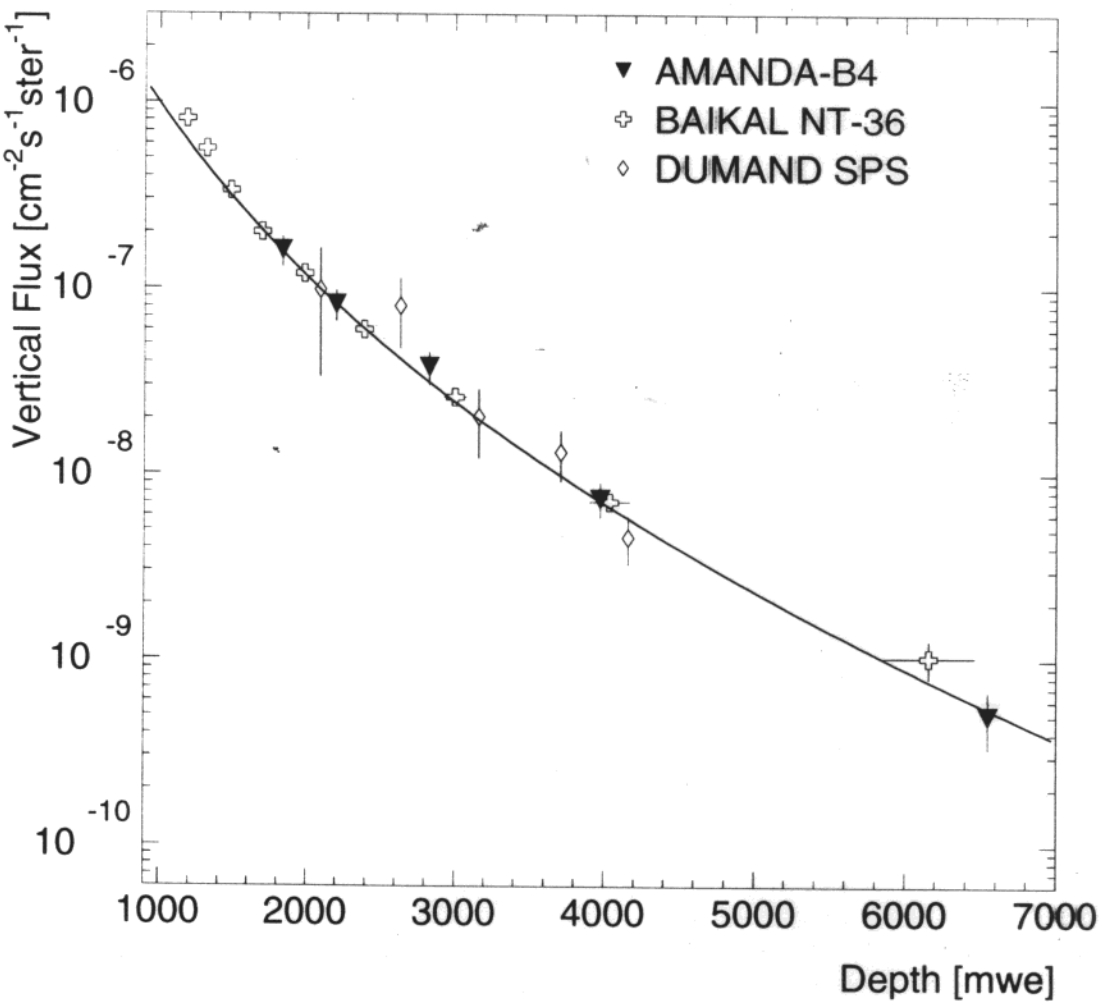
NOTE: B4 is not claimed to be a ν detector!

Muon Flux in AMANDA-B4 (2)

Vertical intensity:

$$I(\theta = 0, h) = I(\theta) \cdot \cos(\theta) \cdot c_{corr}$$

Vertical intensity of muons (DUMAND, Baikal, AMANDA), compared to Bugaev et al.



Reconstruction Procedure

- Hit Cleaning
- Line Fit
- Likelihood-Time Fit
- Likelihood-Energy Fit
- Quality Cuts

Quality Criteria

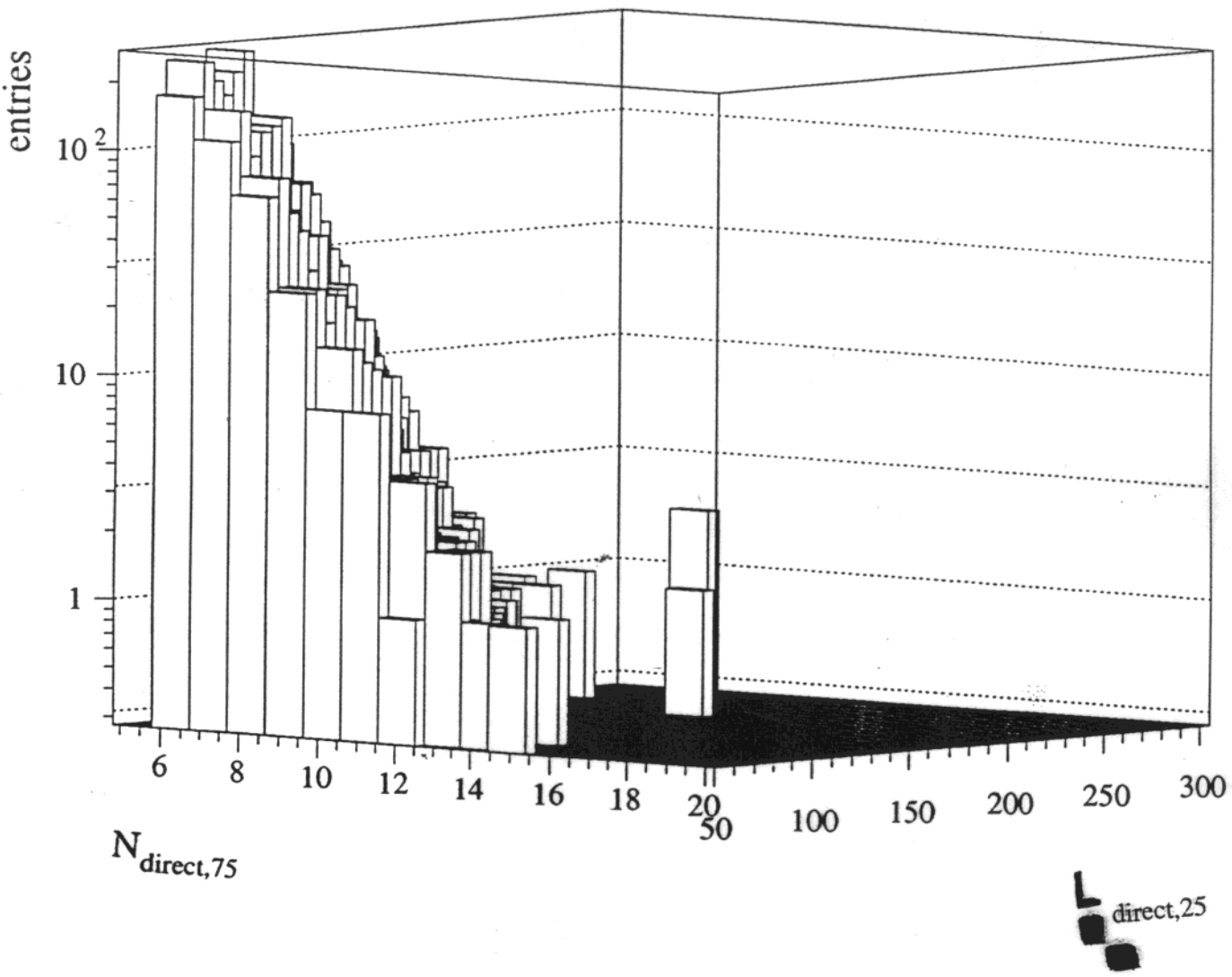
- Velocity of line fit $0.1 < v_{LF} < 1$ m/nsec
- Time likelihood $\mathcal{L}_t > 10$
- Energy likelihood $\mathcal{L}_E > 8$
- Number of „direct hits"
  $N_{dir}(15\,ns) \geq 3$
  $N_{dir}(25\,ns) \geq 5$
  $N_{dir}(75\,ns) \geq 9$
- Projected length of direct hits $L_{dir}(25\,ns) > 200$ m
- z-coord. of COG $|z_{COG}| < 90$ m
- $\theta > 120°$

→ 3 ν candidates

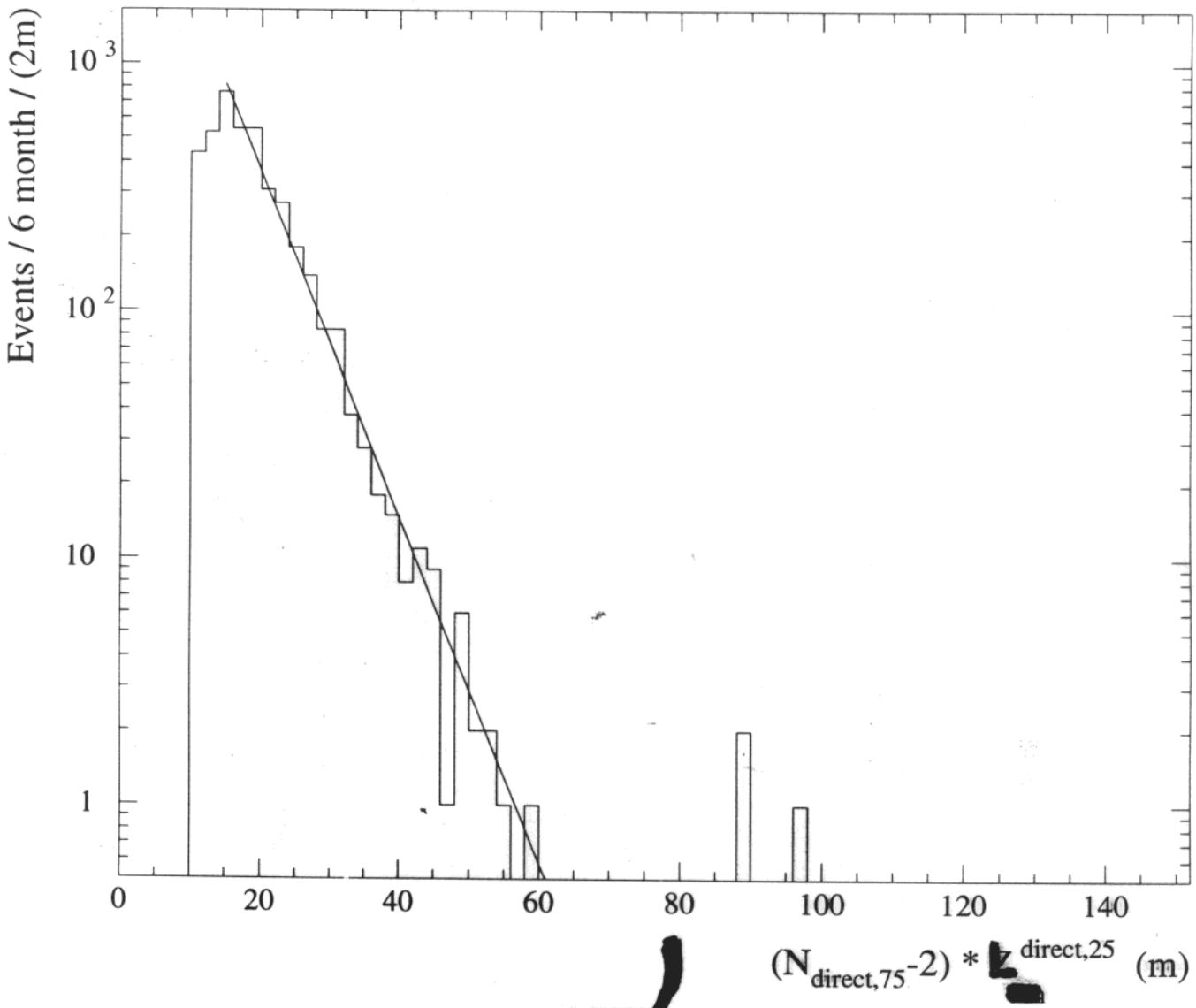
156 days Am.-B4

$3.5 \cdot 10^8$ events

No cut in $N_{dir}(75)$, L_{dir}

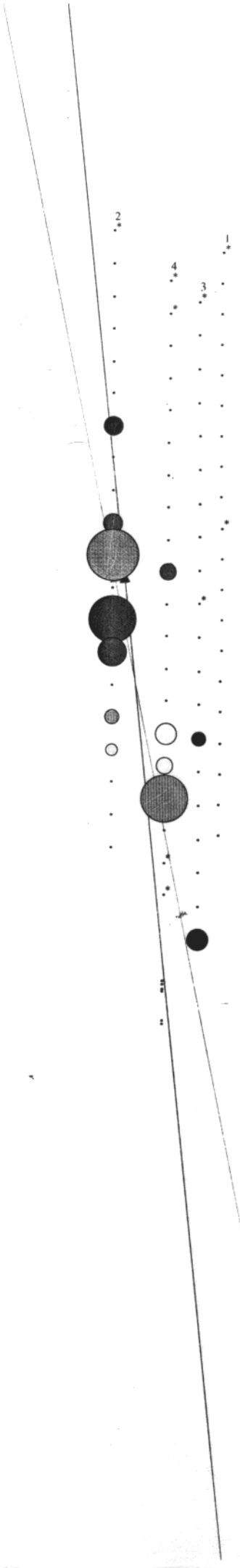


Expected nb. of events from atm. ν ~ 2-8



$P(N_{Fake} \geq 1) = 2.6\%$

$P(N_{Fake} \geq 3) = 3 \cdot 10^{-6}$



Event nr: 147742 Mode: LE Scale: Lin
Electrical Channels
Before Cuts: 13 hit OMs, 13 hits
After Cuts: 13 hit OMs, 13 hits

1570 1
1653
2152 2
2318 1
2401 1
2567 1
2650
2733
2816 1

OM size is ADC.
75< 93< 111< 128< 146< 164< 181< 199<
217< 234< 252< 270< 287< 305< 323< 341<

No external geometry file open.
Using data file ev_ab238_139-96-1_147742.novert.f2k.
Run nr: 0
Year/day: 1996/139
Time since midnight: 42503.3815885 s
The data file contains 1 events.
The array consists of 4 strings.
and 86 OMs.

Tracks available:
Fitted Antimuon 1 (mu+)
Fitted Antimuon 2 (mu+)
Fitted Antimuon 4 (mu+)

Currently displaying information for:
Fitted Antimuon 1 (mu+)

x y z
Vertex pos. : -17.4 -27.5 -6.4 m
Direction : -0.13211 -0.14085 0.98649

Length : Inf m
Energy : 2562.1509112 GeV
Time : 2235.3502098 ns
Theta : 158.7
Phi : 45.8

AMANDA B10

- General Characteristics
- Neutrino Separation
- Search for GRB Coincidences
- Search for Magnetic Monopoles

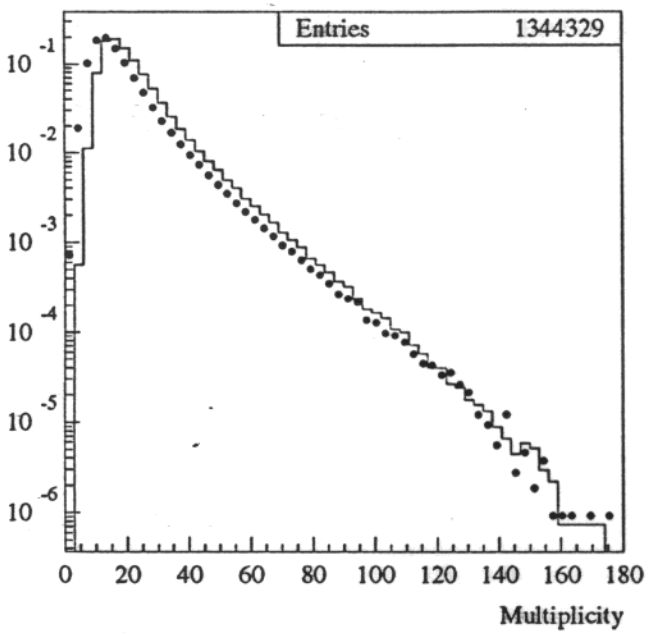
PRELIMINARY !!

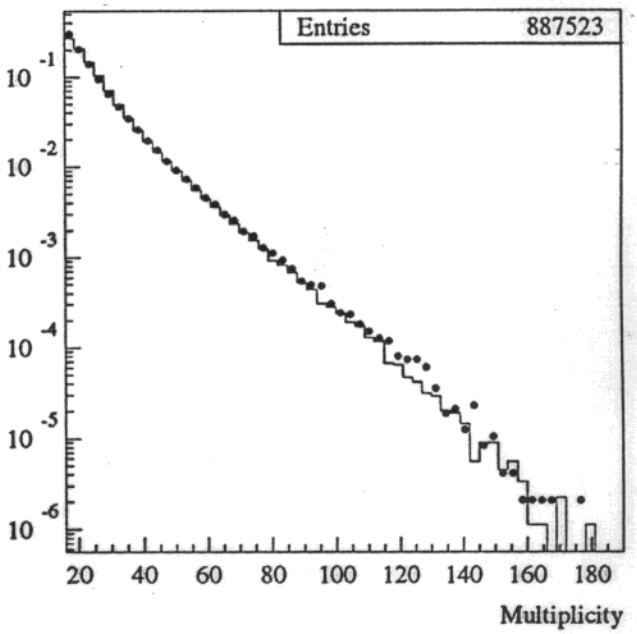
- Only odd days , 1997

Basic Characteristics (1)

Numbers of hit OMs

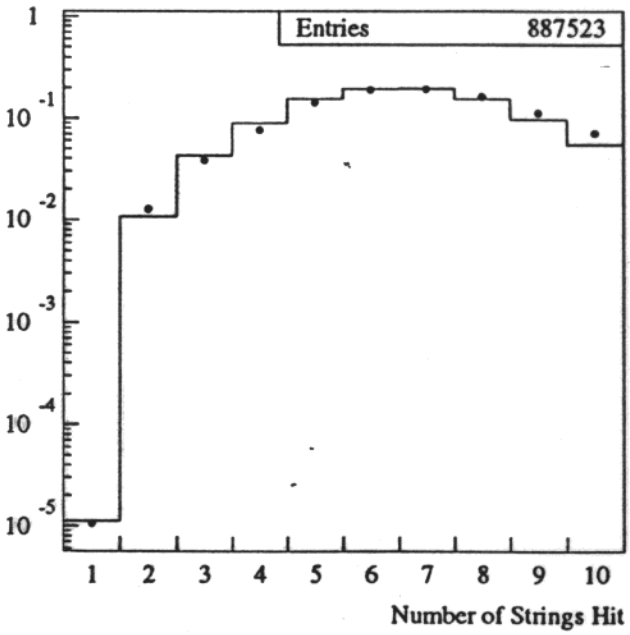
before (left) and after (right) cleaning. Exp: dots, MC: Hist.

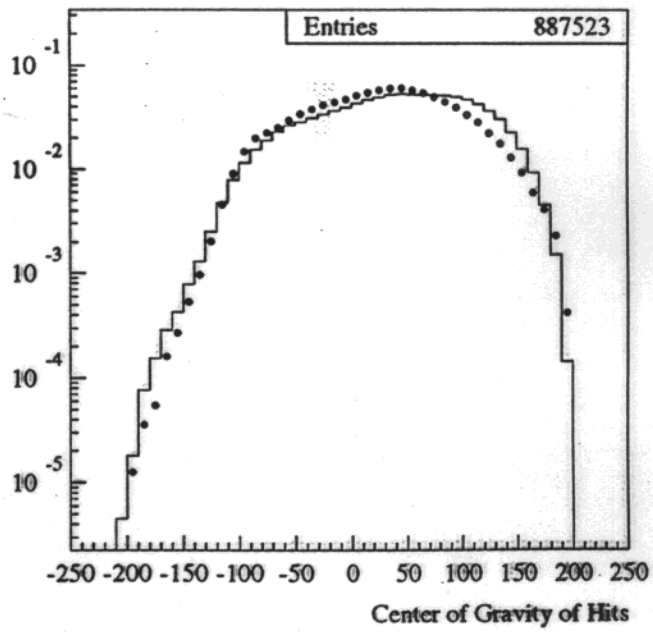




Numbers of hit strings (left), COGZ (right)

Exp: dots, MC: Hist.

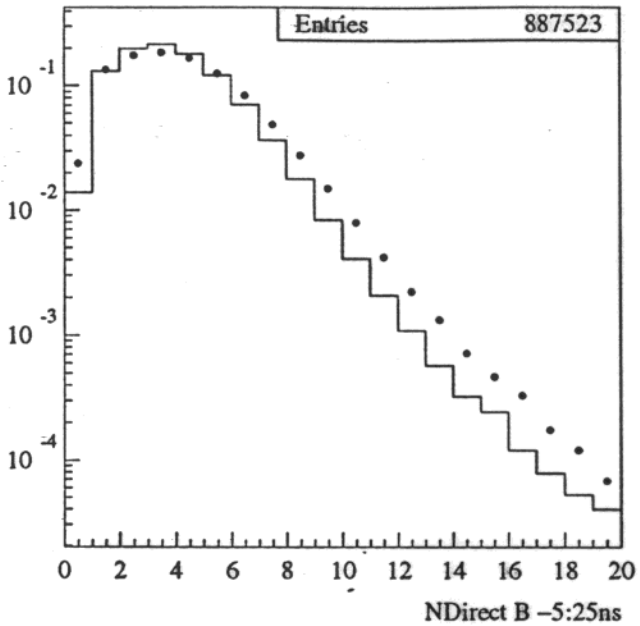


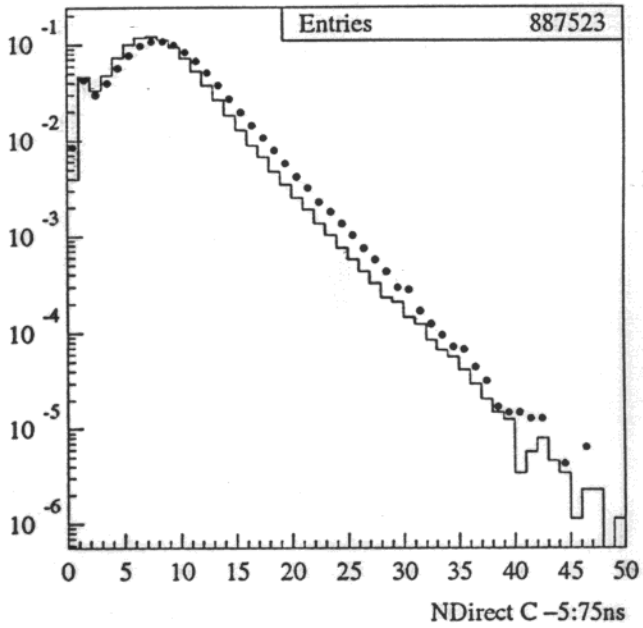


Basic Characteristics (2)

Numbers of direct hits

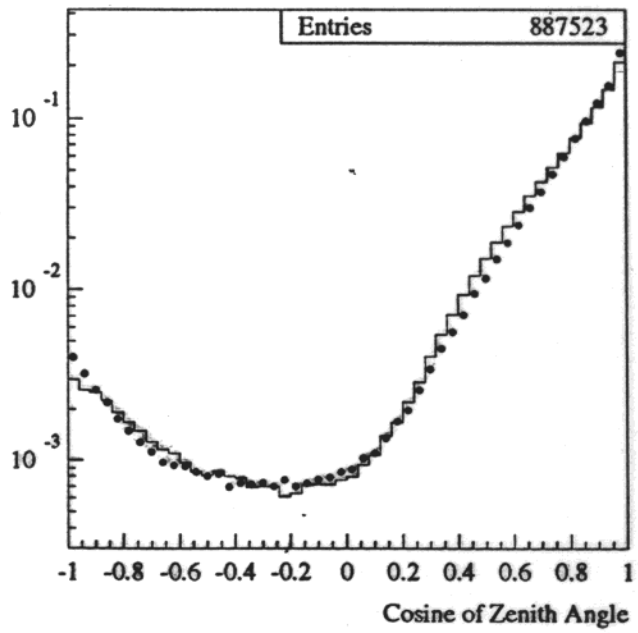
[-5,+25 nsec] left, [-5, +75 nsec] right. Exp: dots, MC: Hist.

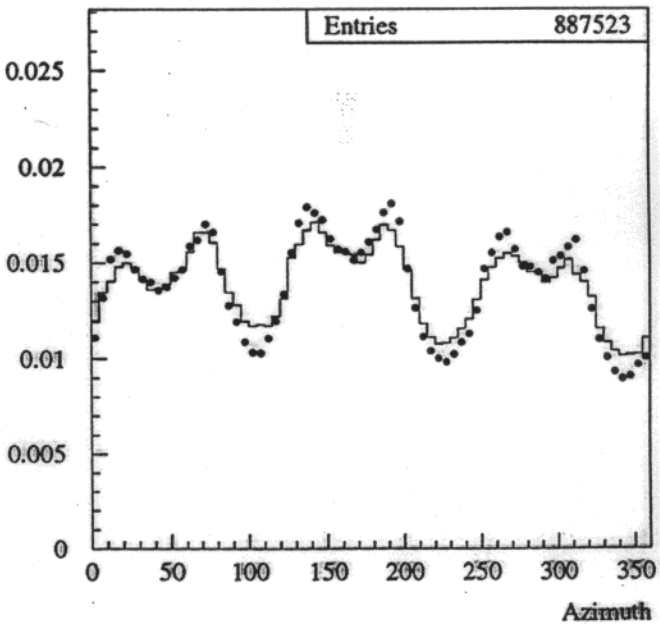




Reconstructed θ (left) and ϕ (right)

Exp: dots, MC: Hist.



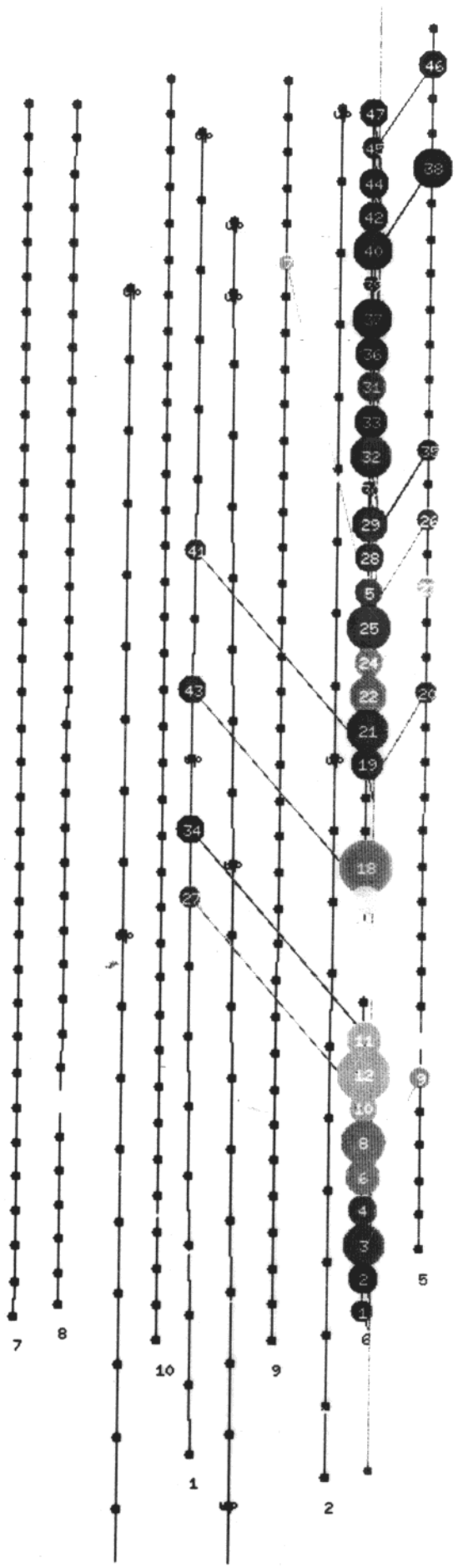


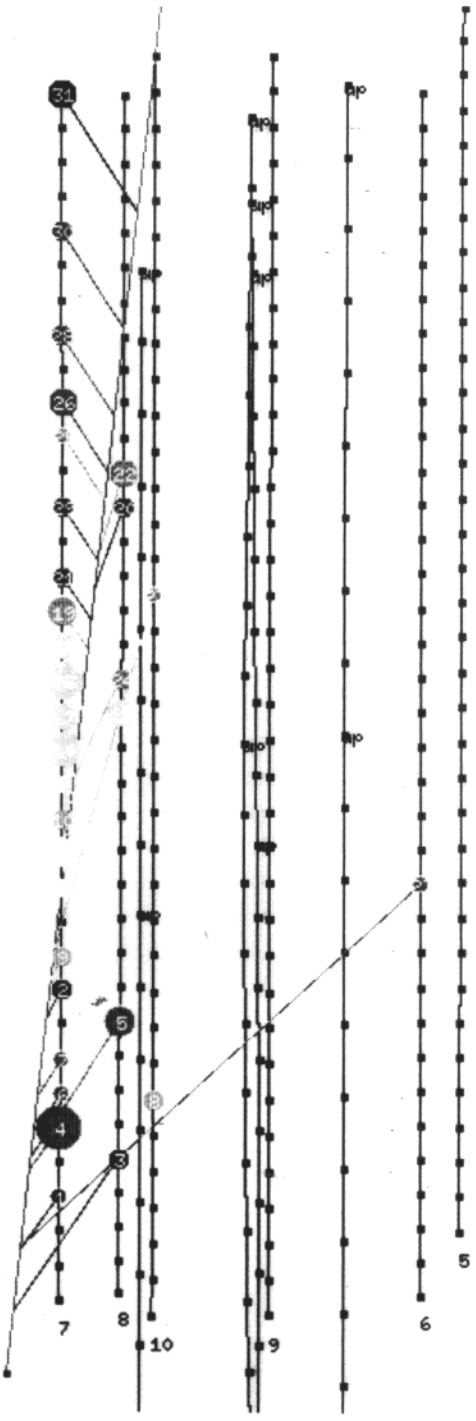
Search for nearly vertical upward muons in B10

Cuts:
1. Zenith of line fit > 172 °
2. ≥ 15 hits in one string (after cleaning)

Odd days in 1997:
- 113 days effective data taking
- 64 262 746 events after basic upward filter
- after cuts 1&2: 26 722 events

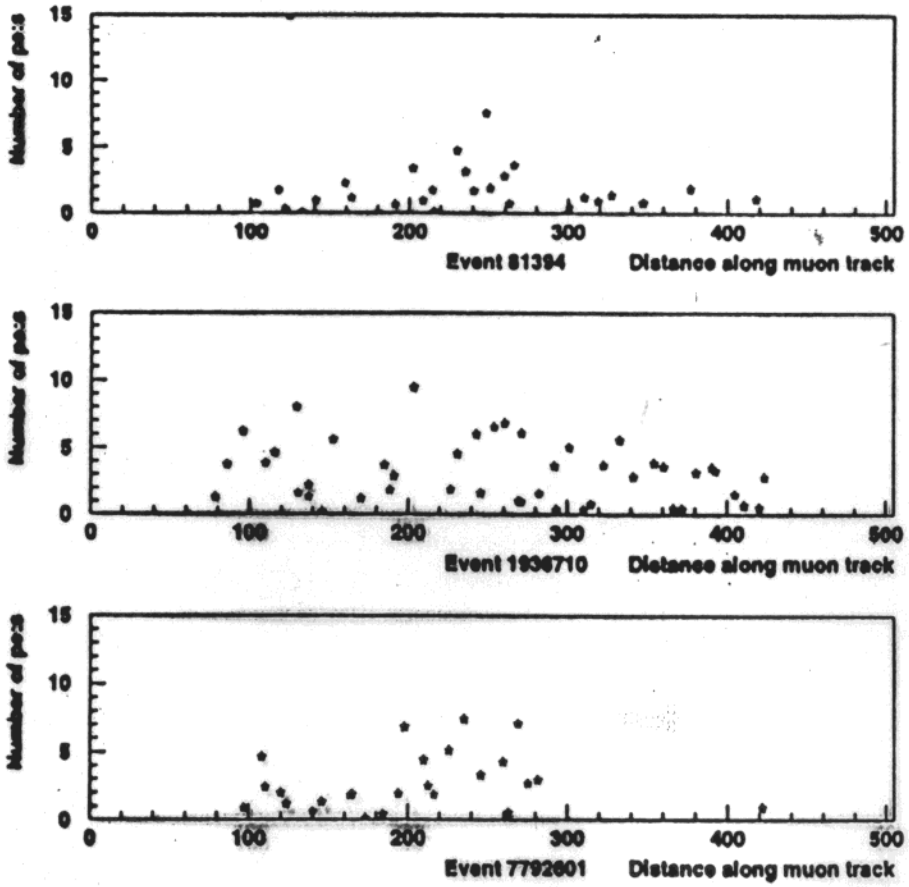
N_{direct} cut	Total No. of events	Upgoing	Downgoing
0	26722	23416	3306
5	384	8	376
6	268	3	265
7	164	3	161
8	97	3	97
9	53	3	50
10	26	2	24
11	13	2	11
12	6	2	4
13	4	2	2
14	2	2	0

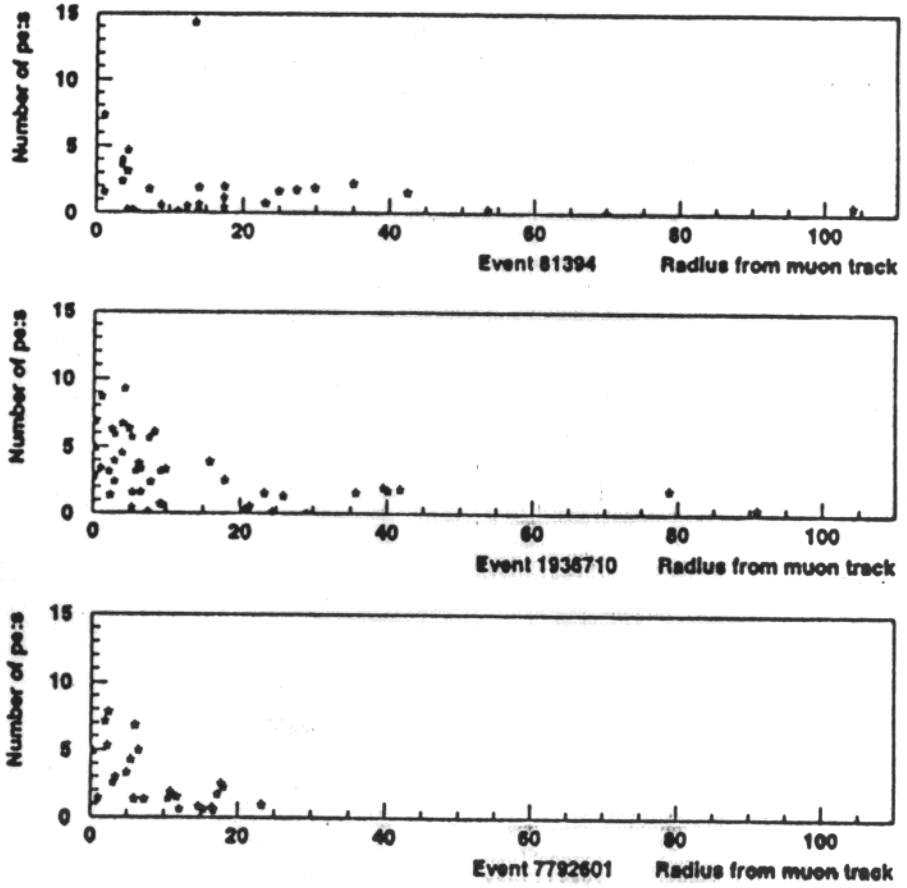




Nice events - details

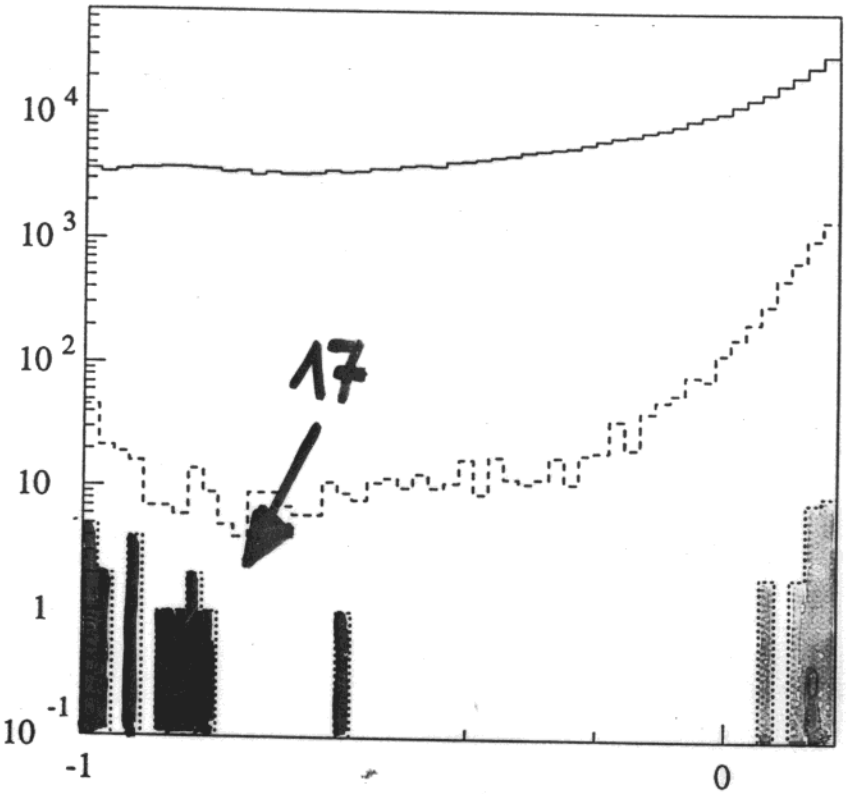
- Number of pe's *vs* distance along / from the track





AMANDA-B10

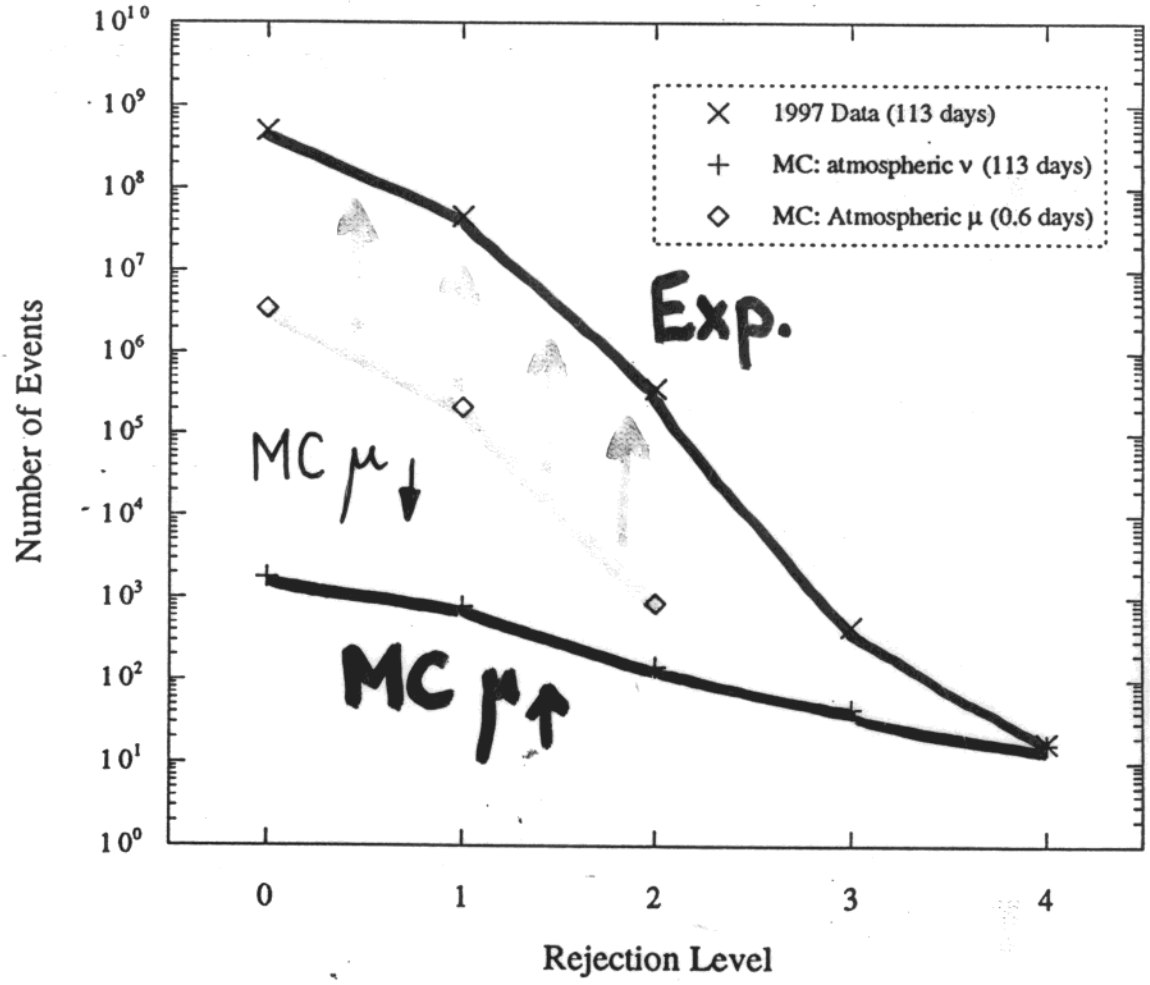
Reconstructed zenith angles of 113 odd days 1997



		Exp.	MC- μ	MC-ν
		113 days	0.6 days	113 days
Not shown:	no cuts	$4.9\ 10^8$	$3.4\ 10^6$	1789
Not shown:	cut level 1	$4.5\ 10^7$	$2.1\ 10^5$	789
Solid line:	cut level 2	$3.5\ 10^5$	853	144
Dashed line:	cut level 3	452	0	44.4
Dotted line:	cut level 4	17	0	16.3

- Will improve considerably with new L parametr. & better cuts

The number of experimental events (113 days), expected atmospheric neutrinos (113 days) and expected atmospheric muons (0.6 days) versus the applied cut level



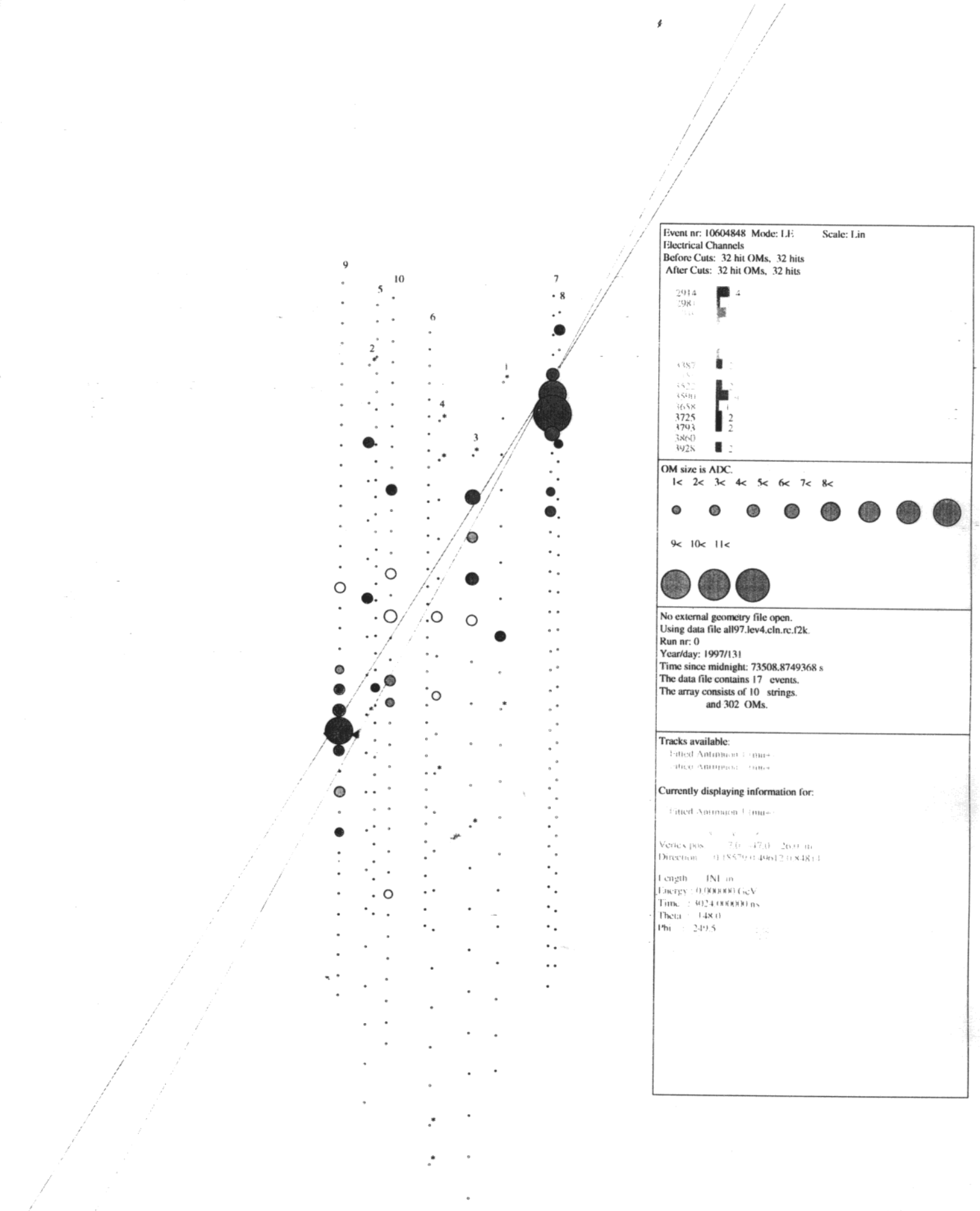
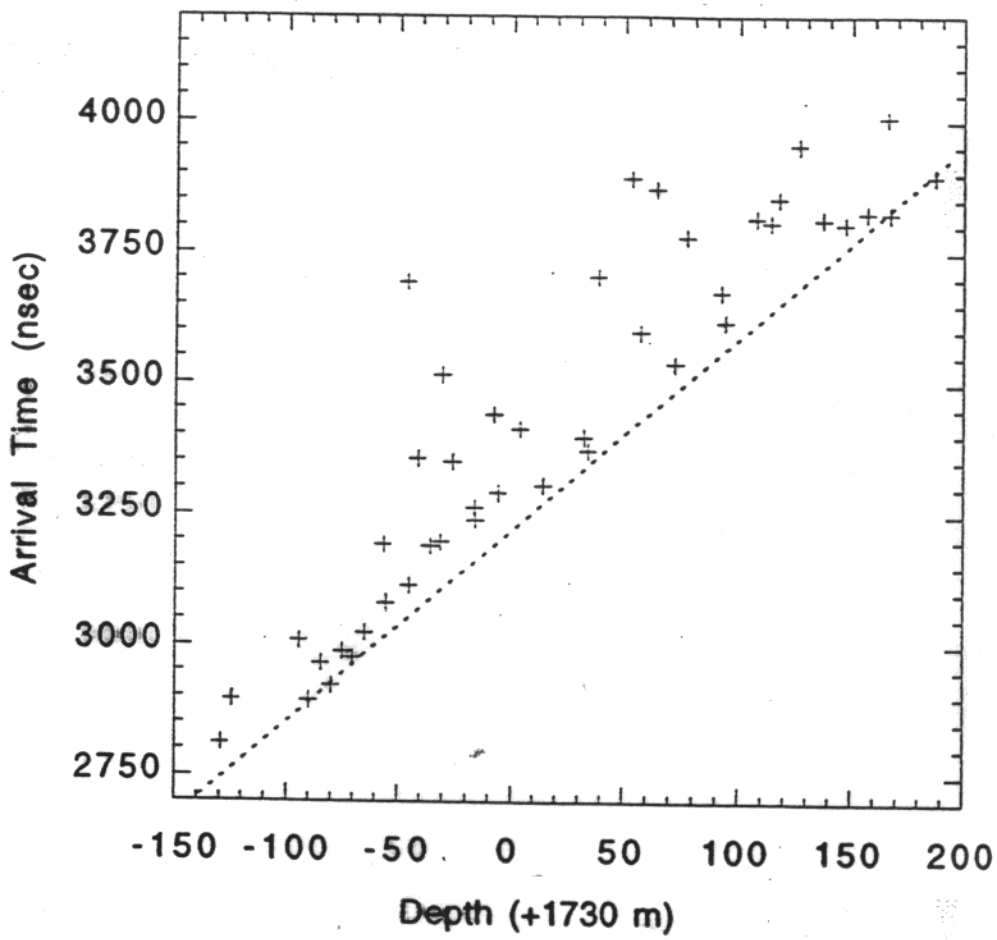


Figure 31: Event 10604848

Event 1197960:

Arrival time of photons versus depth

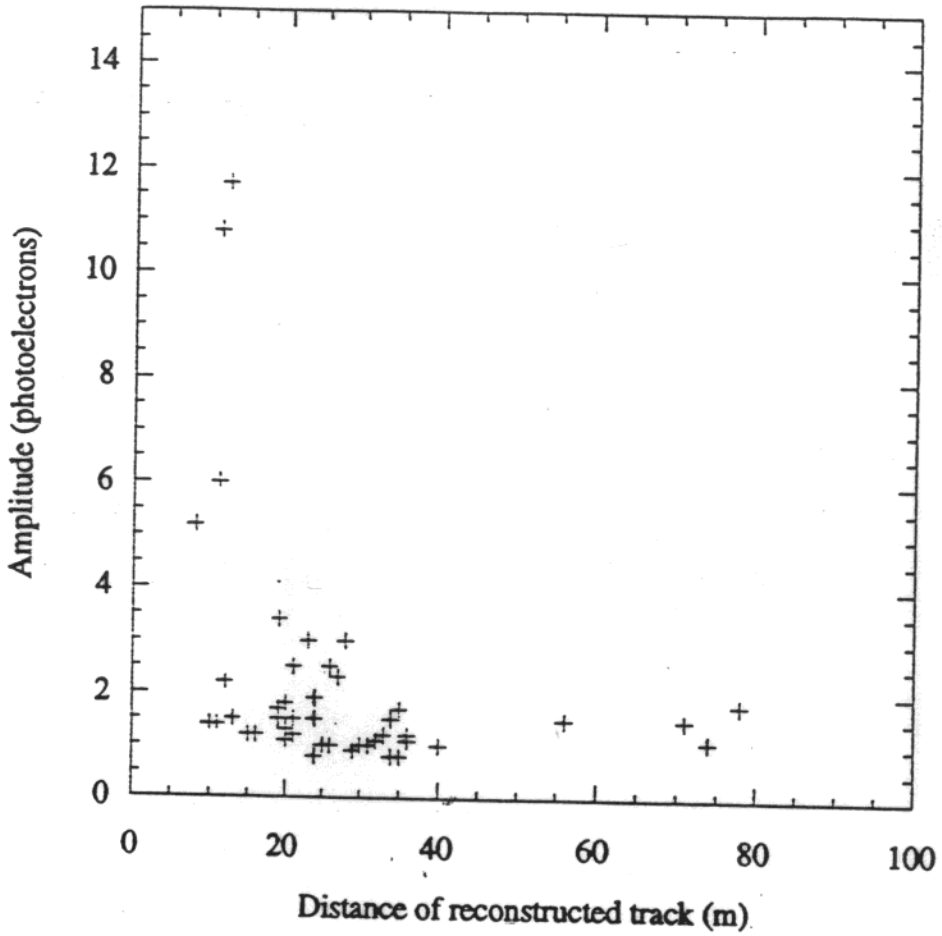


In this graph the absolute arrival time of photons is plotted versus the depth of the observing sensors.

The dashed line illustrates the vertical component of the velocity of the particle, when taking the reconstructed zenith angle of 155 degrees (0.272 m/nsec).
The arrival times of the photons follow the particle speed over a vertical distance of 350 m!

Event 1197960:

Amplitude versus distance to track

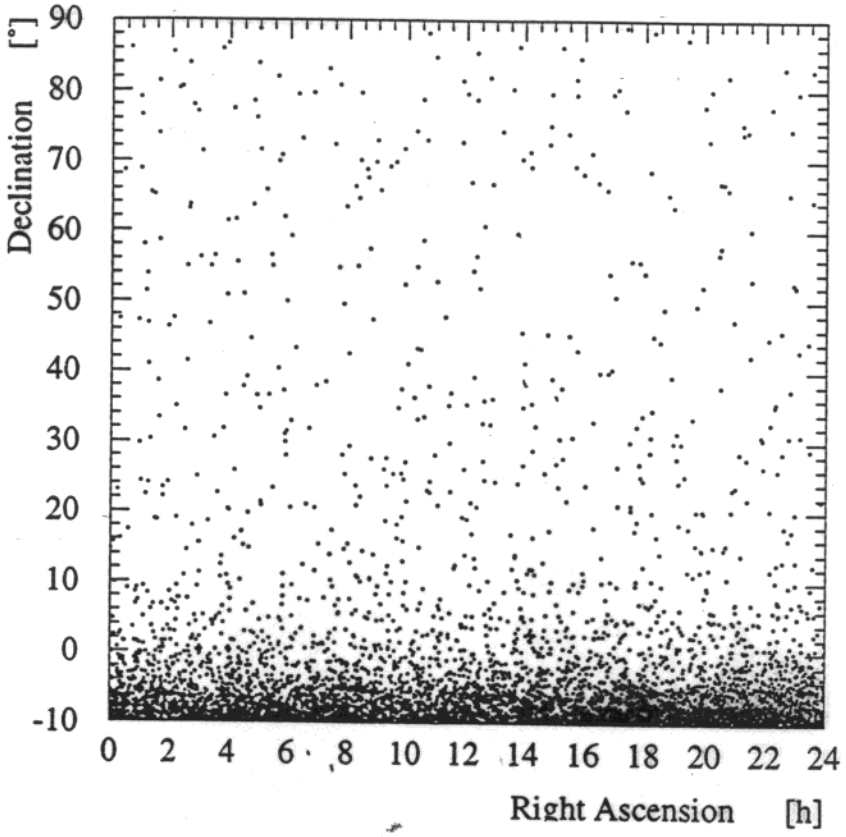


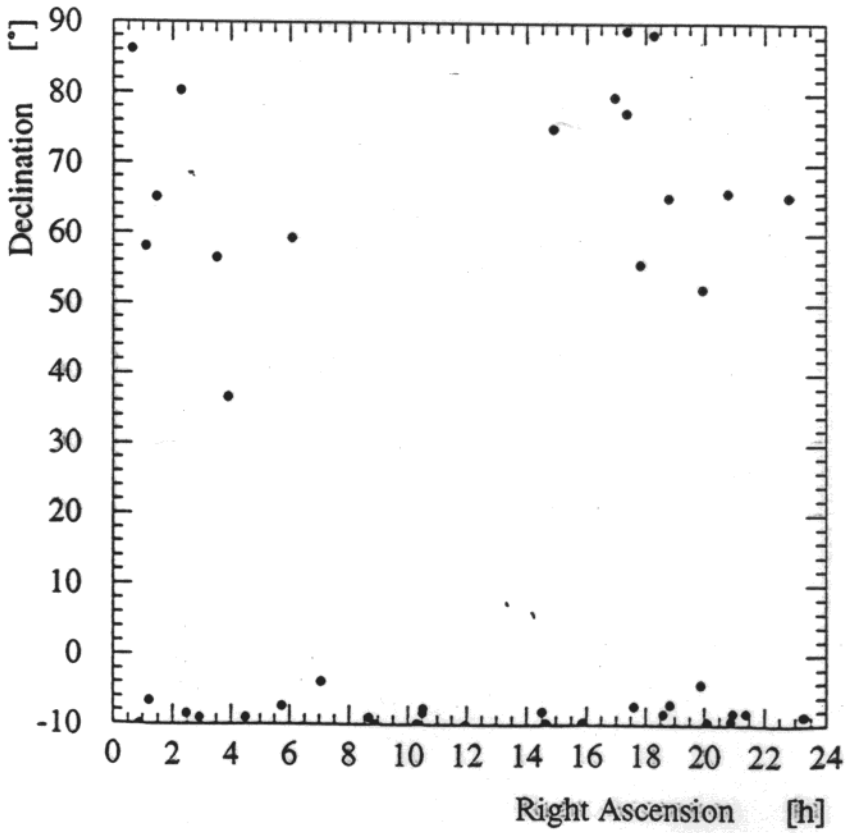
The number of measured photo electrons in each photomultiplier is plotted versus the distance of the track.

This plot provides additional evidence, that this event is indeed a neutrino induced muon. The amplitude information has not been used neither for reconstruction not for the event selection.

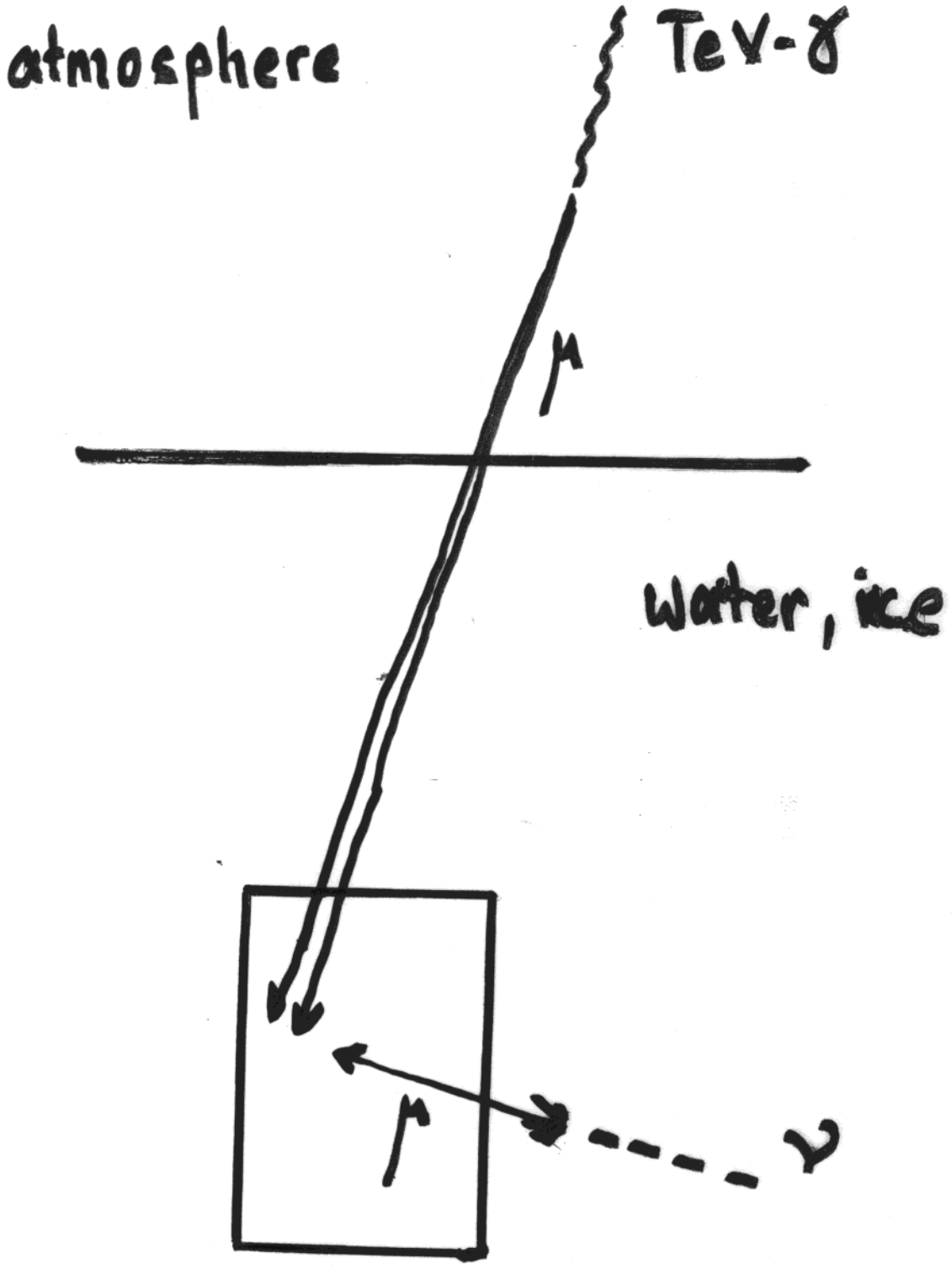
Sky Plot

top - after cut level 3, *bottom* – after cut level 4





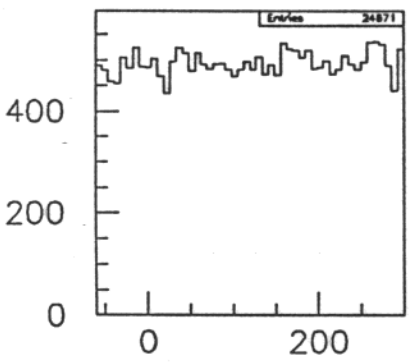
Signals in Coincidence with GRBs



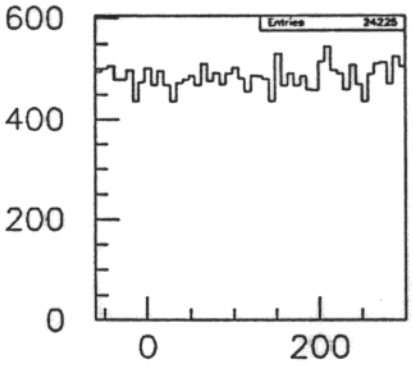
GRB/B10 Muon Coincidence Analysis

304 BATSE bursts in 1997, GRB sample (-1,+5 min)
Amanda on at 70%, use only odd days

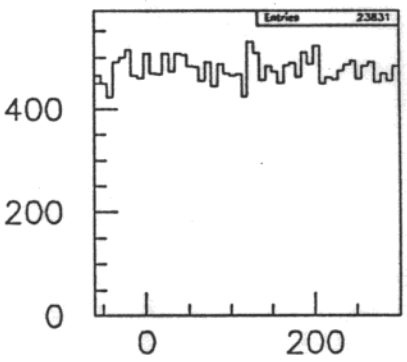
Event rate vs. time (-1,+5 min) for 9 GRBs



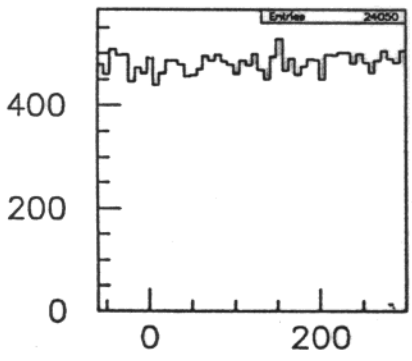
GRB 6117



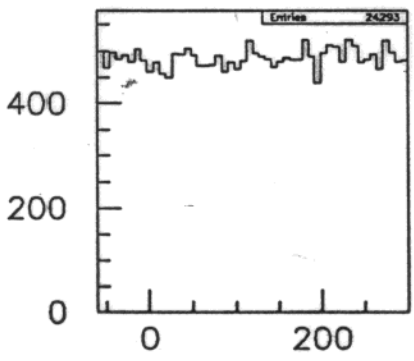
GRB 6119



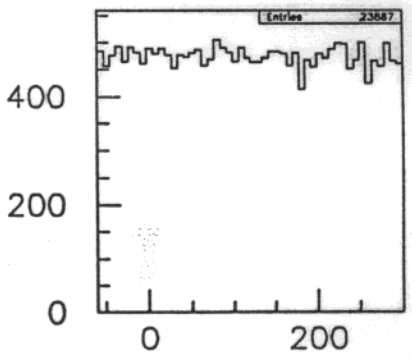
GRB 6129



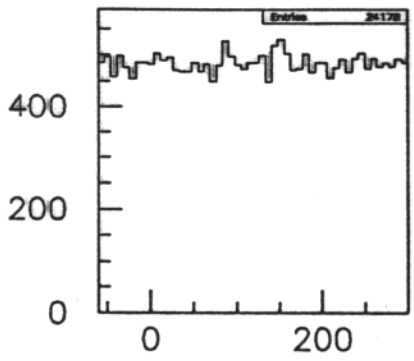
GRB 6135



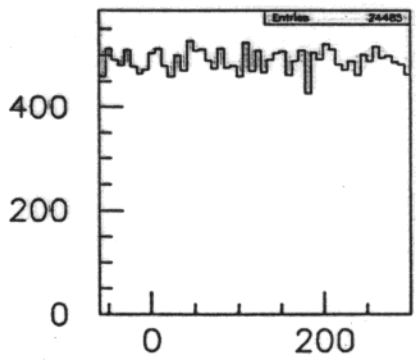
GRB 6136



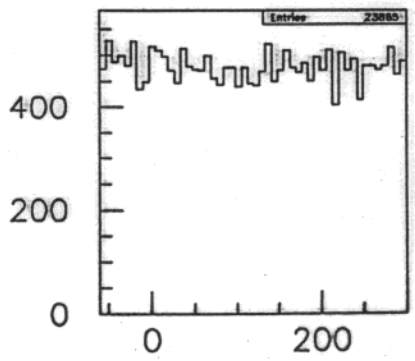
GRB 6137



GRB 6141



GRB 6142



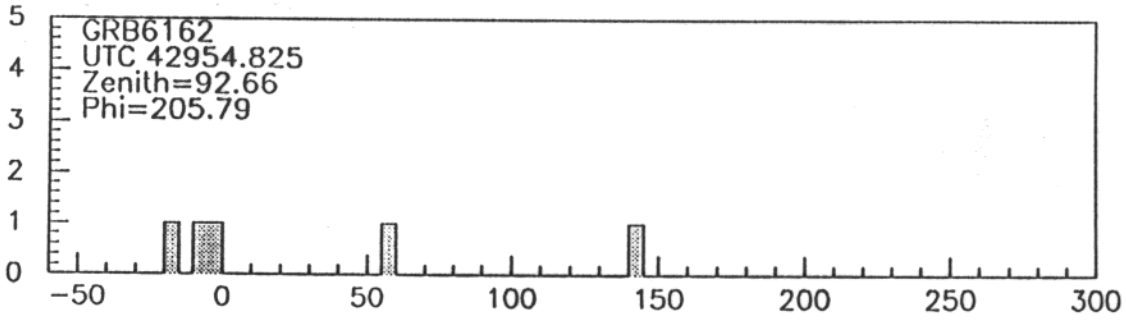
GRB 6147

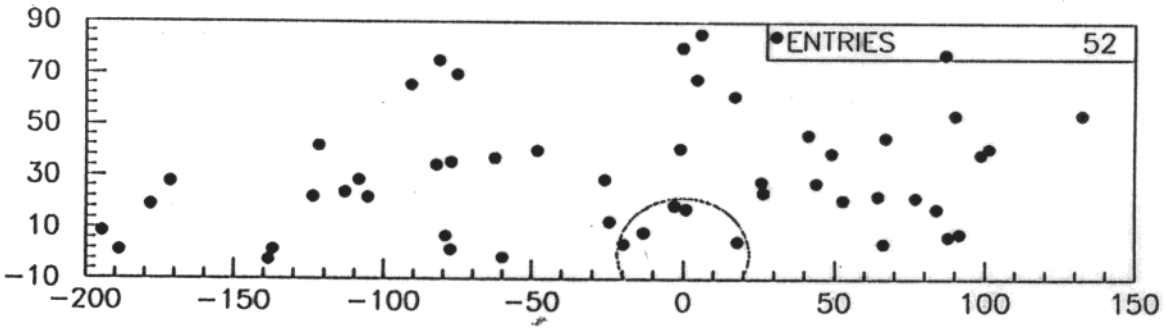
GRB/B10 Muon Coincidence Analysis

Example: ***GRB 6162***

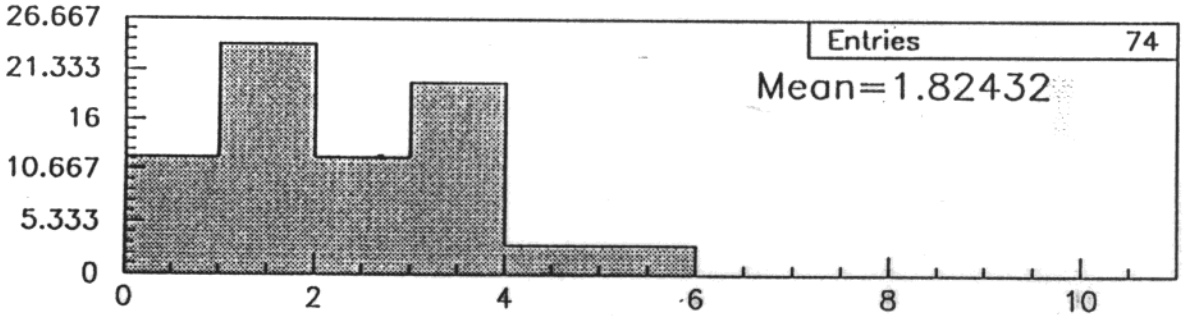
zenith = 92.66°, azimuth = 205.79°

5 events in signal region → not significant





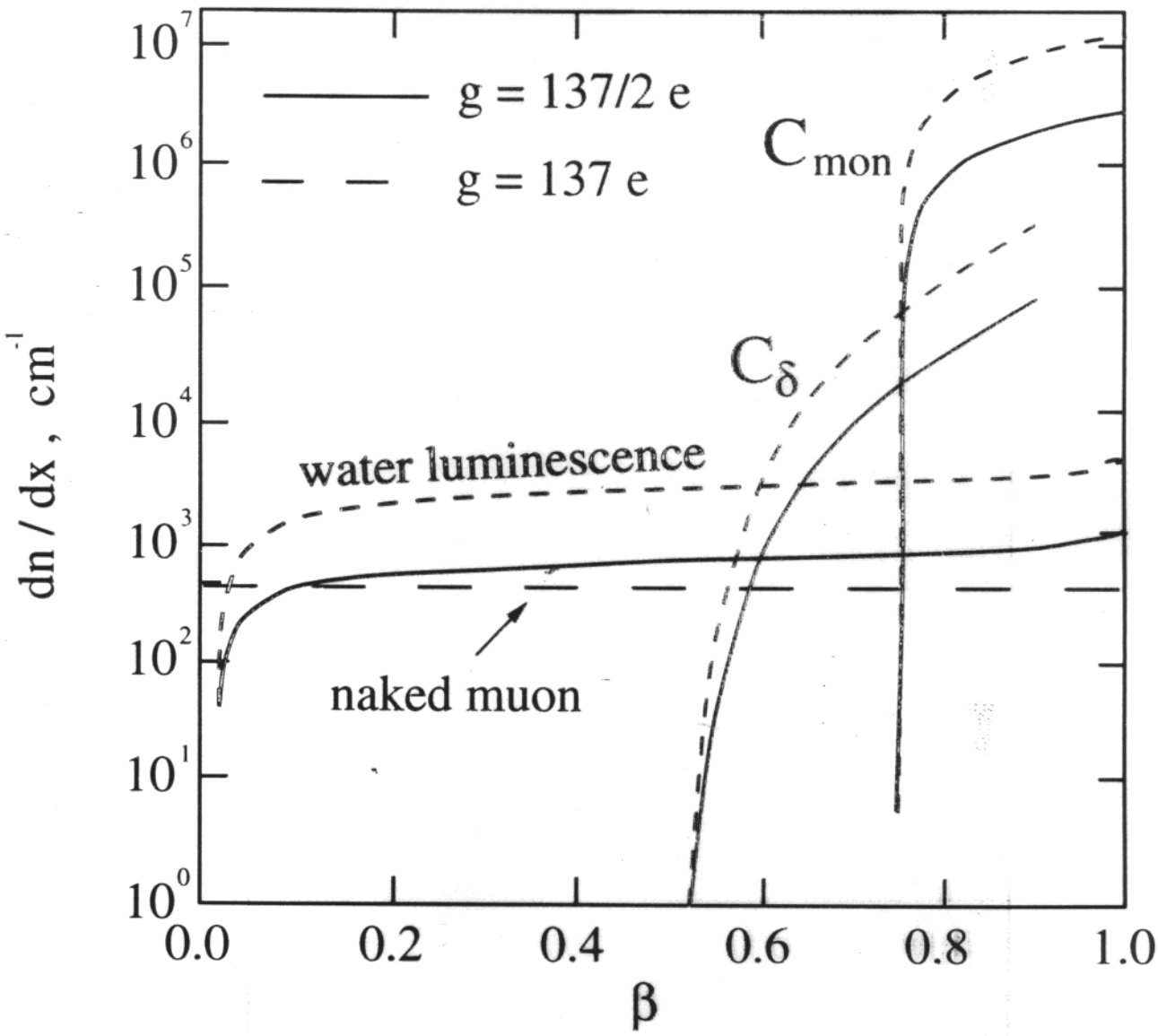
(zenith(1)−92.66) VS. (azimuth(1)−205.79)



Bkg 6 Minute Count Distribution

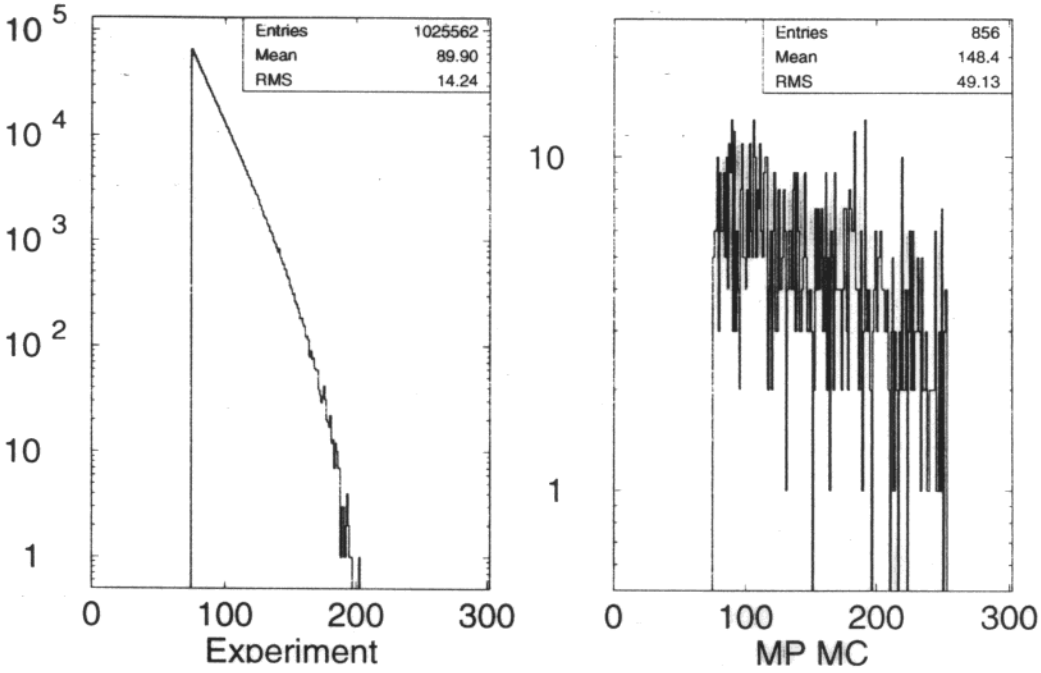
** No significant coincidences found at all. **

Magnetic Monopoles
Light Generation in Water

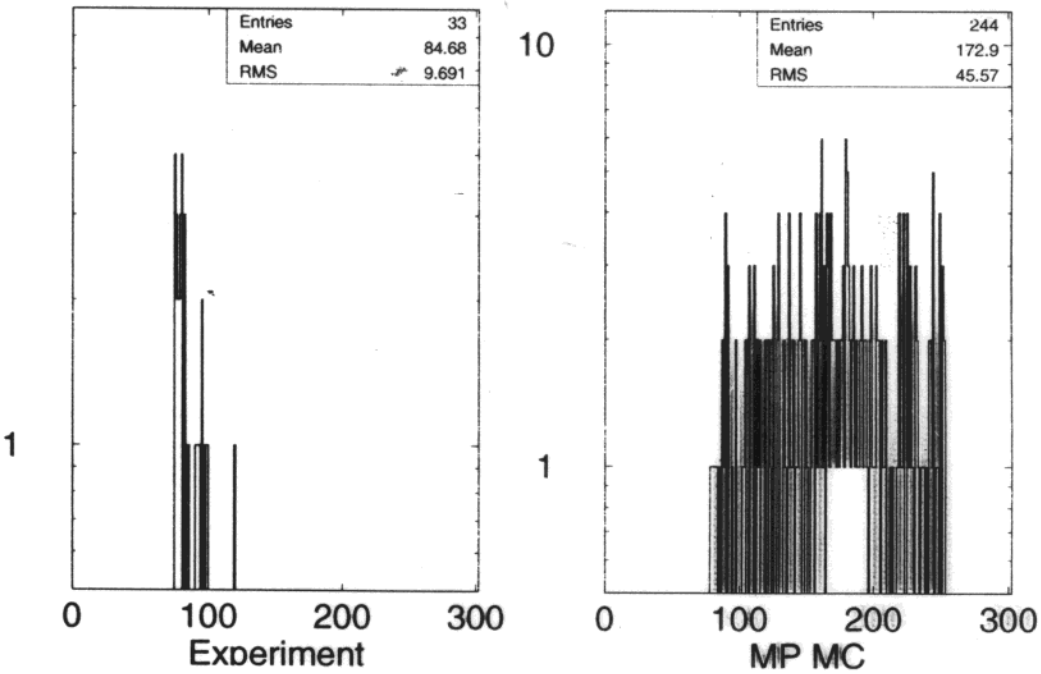


AMANDA B10, 33 days uptime

Nch > 75



Nch > 75, $\Theta > 60$, $0.2 < v_{LF} < 0.35$



Acceptance for magnetic monopoles $(k = 1)$

after

- Nch > 75
- $\Theta > 60$
- $0.2 < v_{LF} < 0.35$

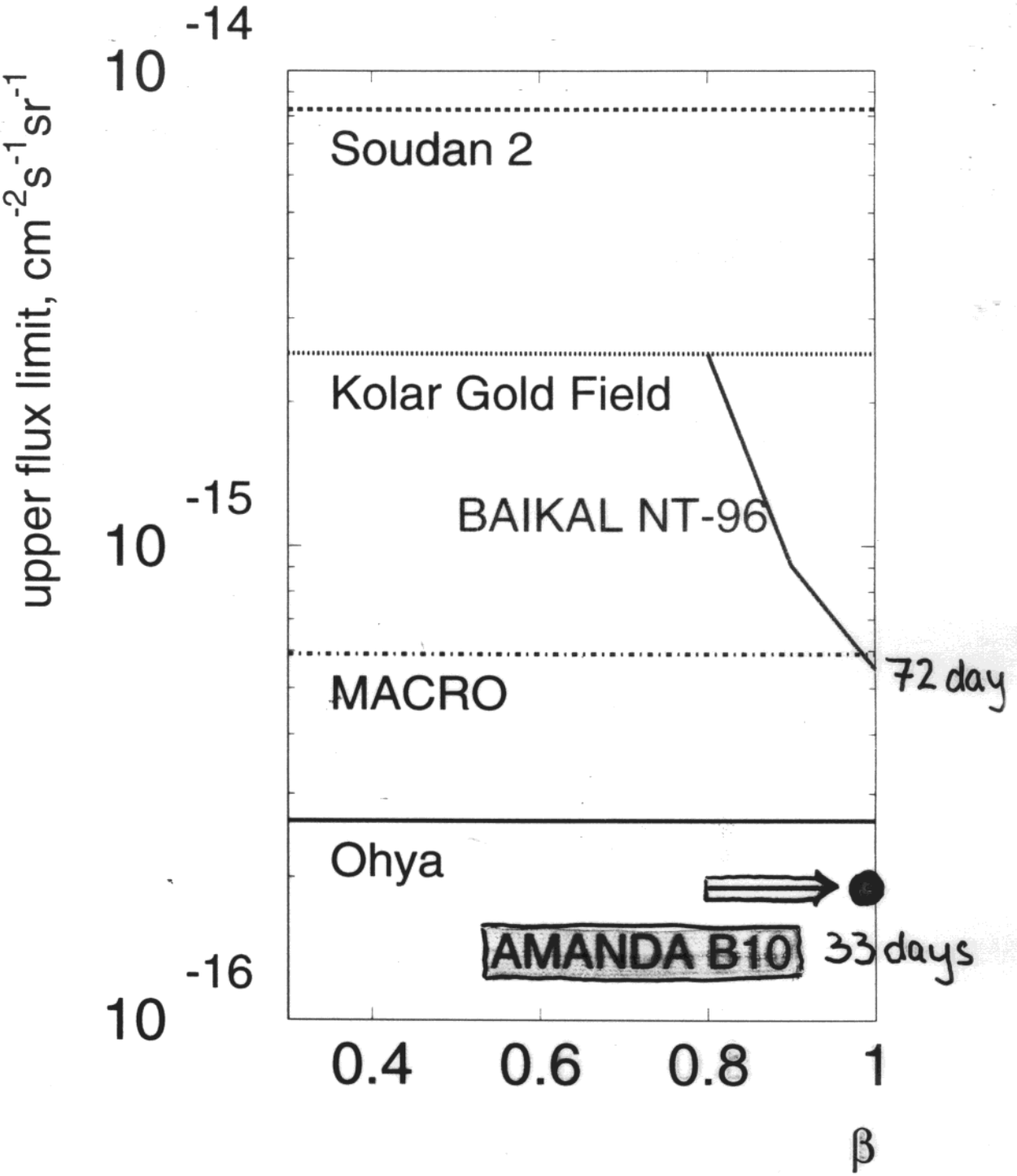
$$A = 4.62 \cdot 10^5 \mathrm{m}^2\mathrm{sr}$$

- Life Time $=$ 33 days
- Duty Factor $= 0.9$

$\Rightarrow$ Upper limit for monopole flux (90% C.L.)

$$\begin{aligned} \phi &\leq \frac{2.3}{4.62 \cdot 10^9 \mathrm{cm}^2\mathrm{sr} \cdot 0.9 \cdot 2.85 \cdot 10^6 \mathrm{s}} \\ &= 1.9 \cdot 10^{-16} \mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{s}^{-1} \end{aligned}$$

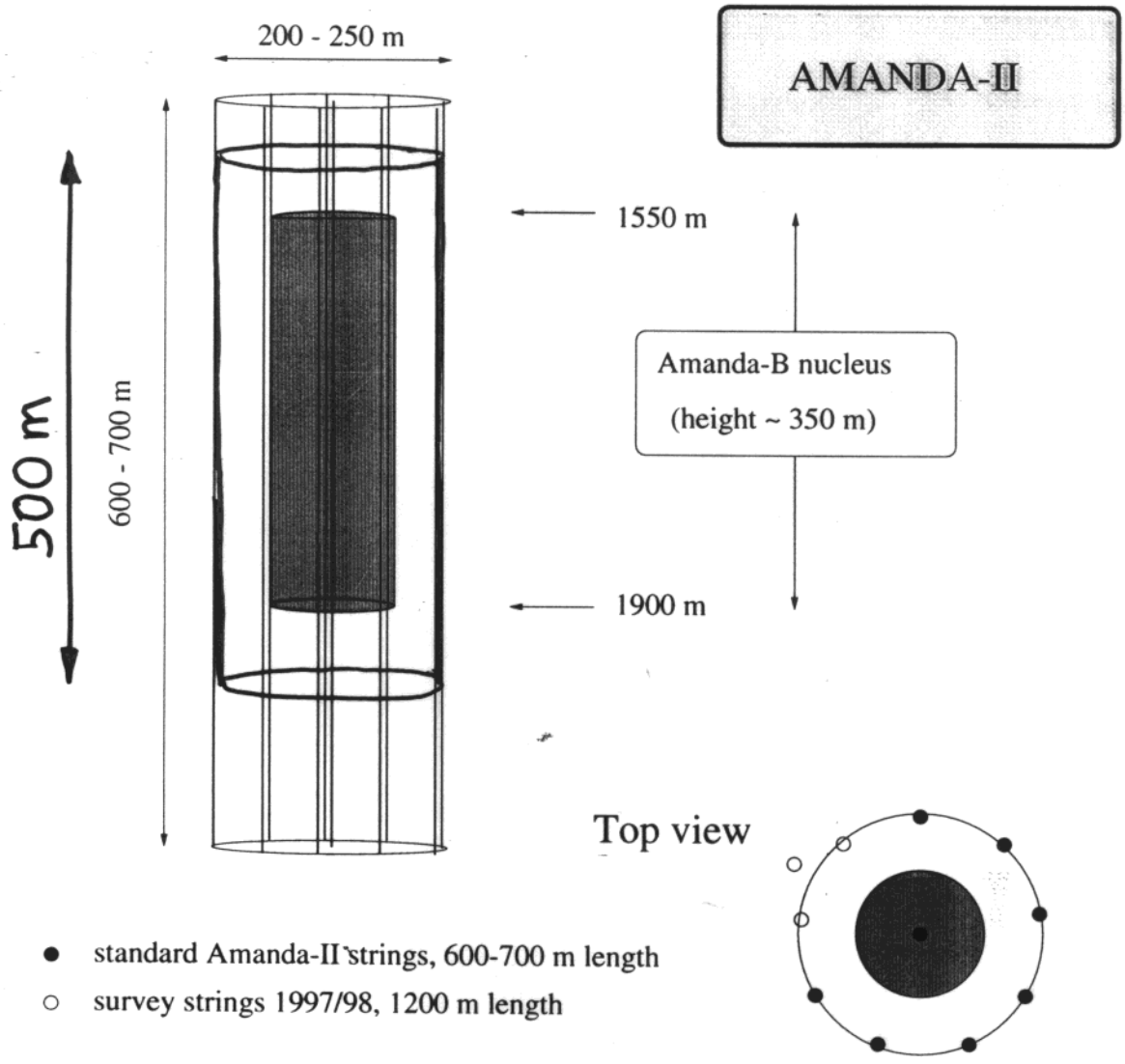
Flux Limit (90%C.L.)



Future

- Amanda-II
- DeepIce Center
- IceCube

AMANDA-II design



- standard Amanda-II strings, 600-700 m length
- survey strings 1997/98, 1200 m length

$A_{eff} \sim 25\text{-}30 \cdot 10^3\ m^2$ (1 TeV)

AMANDA-II:

- Configuration

1995-97	97/98	99/2000
B10	3 strings	7 strings, 492 m 42 OM per string

- Effective area 1 TeV: $3 \cdot 10^4$ m^2

- Technology

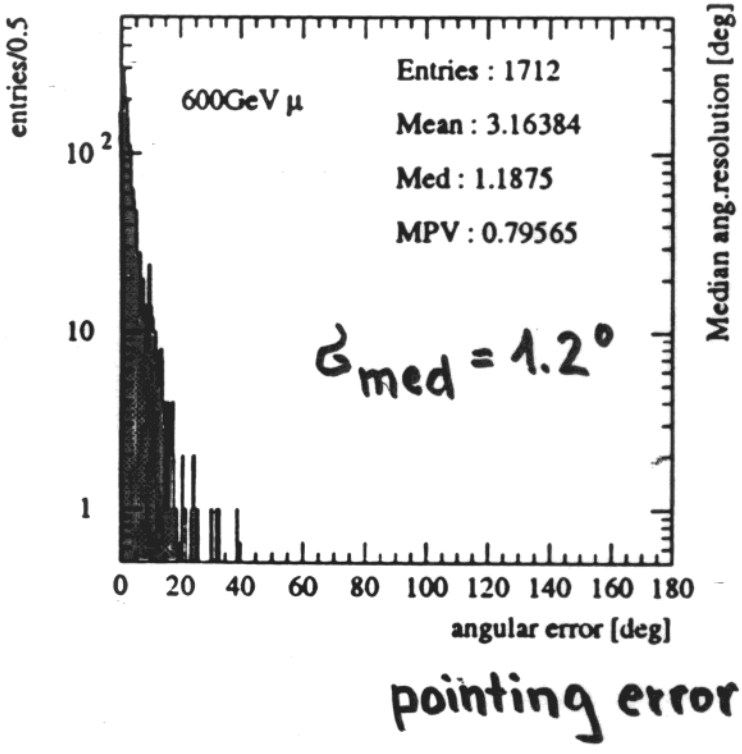
  - Basically analog-hybrid (fiber + electr.) , passive LED

  - some analog-hybrid OMs with active LED/LD

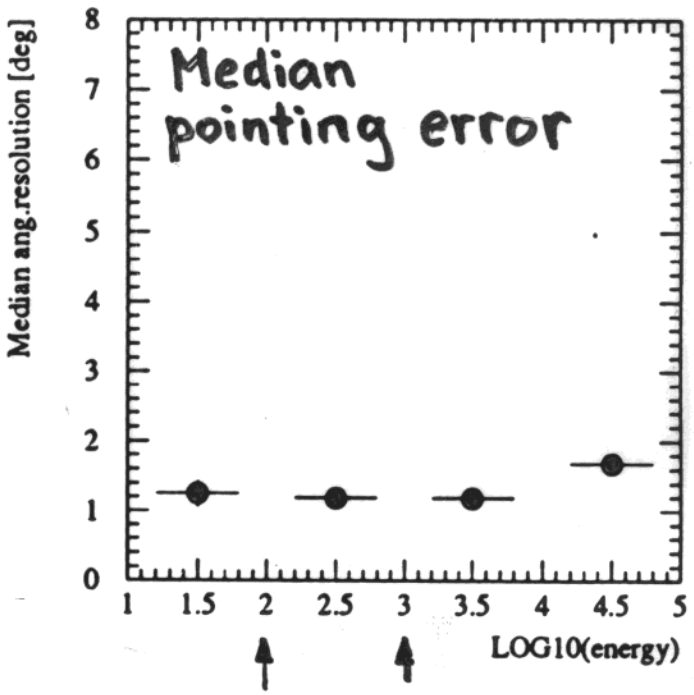
  - 25-50 Digital OMs

AMANDA-II (strawman)

POINTING:



pointing error



0.1 1 10 TeV

Eff. Area ~ $50 \cdot 10^3$ m^2 (5 TeV)

DeepIce
Science and Technology Center

High Energy Neutrino Astrophysics
(AMANDA) 7.4 M$/5 years

Cherenkov Radio Emission (RICE)

Cosmic Ray Physics (SPASE)

Seismology

Glaciochemistry & Paleoclimatology

Cosmogenic Nuclides, Ice Age Periodicity &
Extraterrestrial Materials

Ice Properties, Glaciology & Paleothermometry

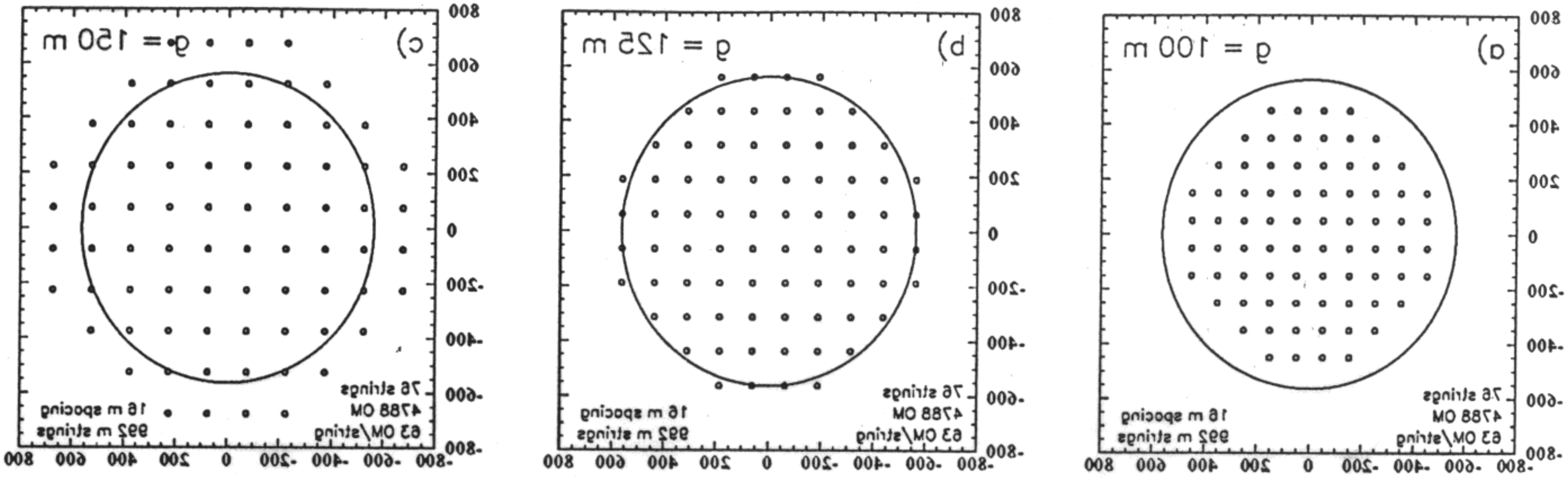
Psychrophylic Microbes

Drilling Technology

400 → 40 → 16 ----→ 8-10

↑

Site visit Berkeley End Febr.



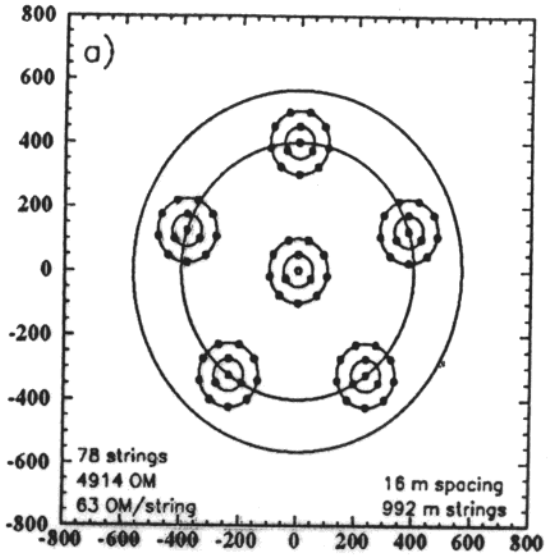
Muon Energy E_{μ}	100 GeV	1 000 GeV	10 000 GeV
Geometry 1	585	855	887
(grid 100 m)	**61**	**518**	**576**
Geometry 2	150	841	1030
(grid 125 m)	**14**	**503**	**651**
Geometry 3	35	691	1080
(grid 150 m)	**4**	**353**	**642**

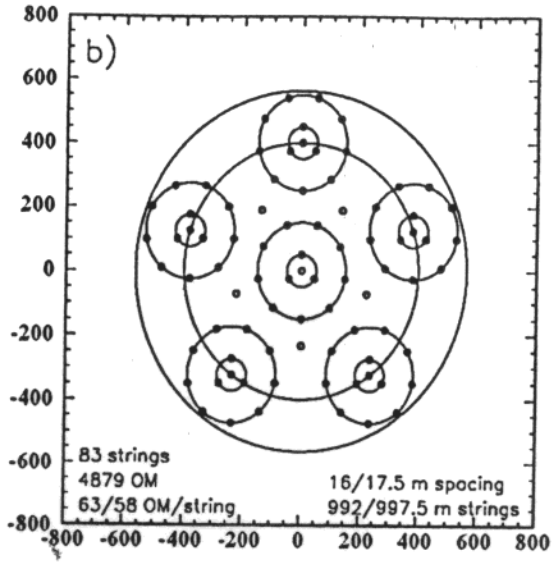
Ice cube

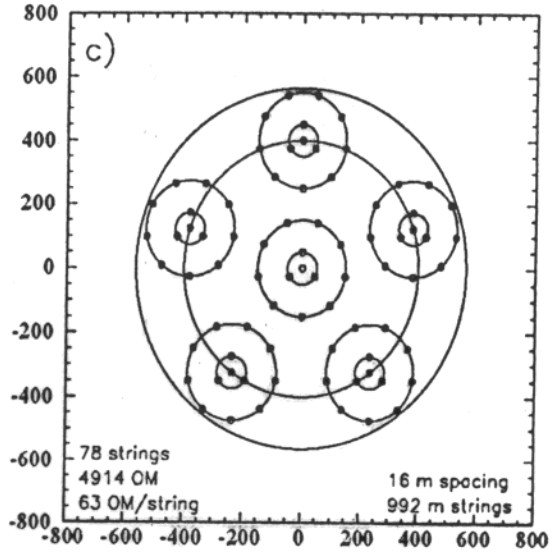
~5000 8" OM without WLS

Trigger area →

After reco with 3° cut →







Muon Energy E_μ	100 GeV	1 000 GeV	10 000 GeV
Geometry 9	*828*	*832*	*886*
(cluster)	**63**	**300**	**345**
Geometry 10	*800*	*837*	*881*
(cluster + single)	**75**	**353**	**401**
Geometry 11	*502*	*889*	*984*
(blown cluster)	**52**	**485**	**528**

Conclusions

- Detector: 10 + 3 strings
- Calibration: $\Delta t_0 \sim 5\,\text{nsec}$, $\Delta x, y, z \sim 0.5\,\text{m}$ } B10

- Results
  - 3(4) ν candidates from B4
  - Very preliminary results from B10
    - first clear ν candidates. Agreement with expectations at this analysis level. Will improve considerably with advanced analysis!
    - no coincidences with GRB observed
    - $\Phi_{\text{Monopole}}(\beta \approx 1) < 2 \cdot 10^{-16}\ \text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1}$

- Future
  - Upgrade Amanda-II in 99/00 ($\sim 3 \cdot 10^4\ \text{m}^2$)
  - IceCube ($\gtrsim 5000$ PMT) by 2007/08