Future High Energy Neutrino Telescopes

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ν2000, Sudbury

1. Physics and Methods
2. Underwater/Ice Detectors
3. IceCube: Example for KM3
4. Acoustic and Radio Detection
5. Low and Super-high Energies
6. Conclusions

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Physics and Methods

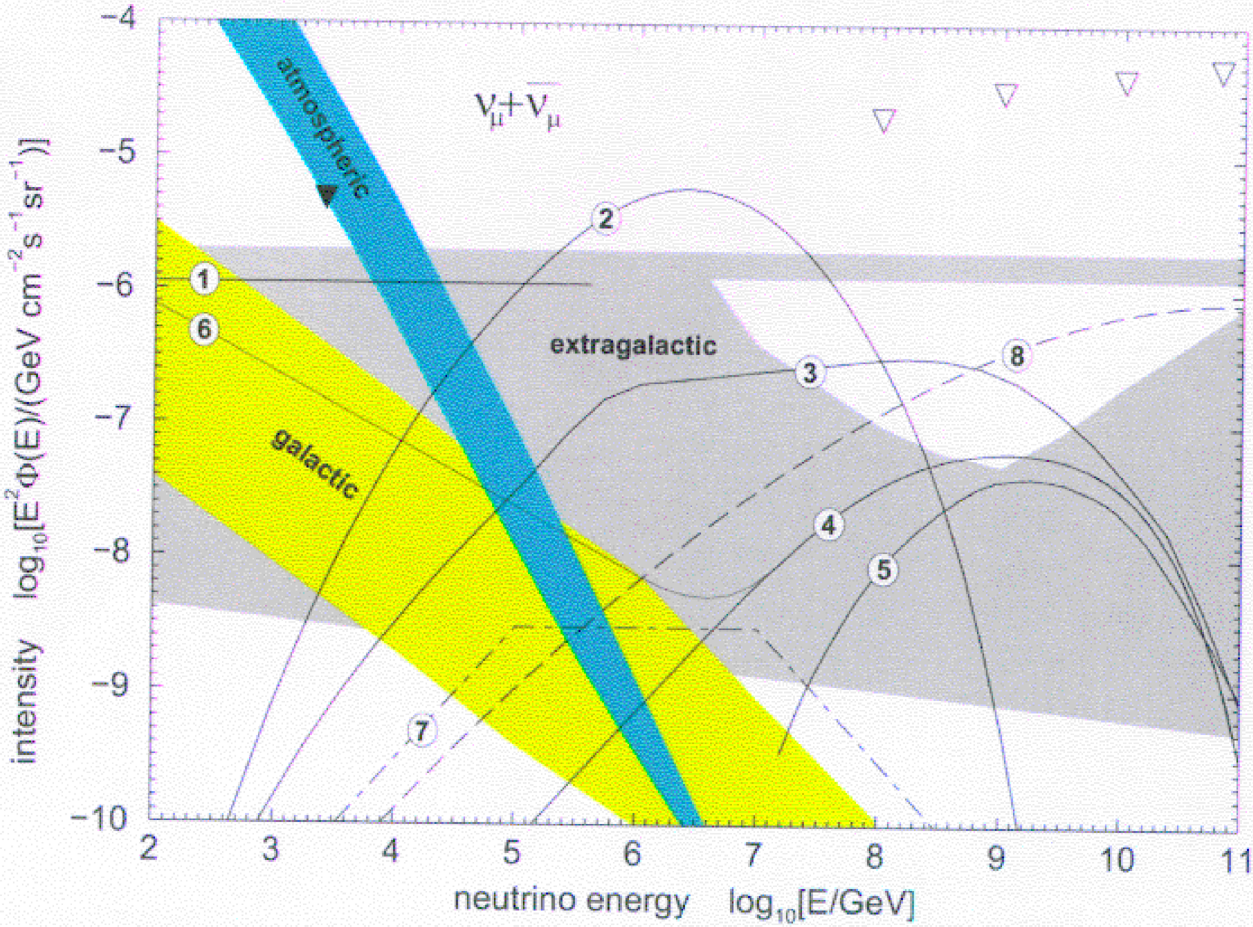
Physics

- AGN
- GRB
- galactic sources
  (SNR, young SN,
  microquasars,..)
- SN bursts
  (MeV signal)
- ν from topological defects (TD)
- [redacted] ...

- ν oscillations
  using ν from accelerators, atmosphere or extraterrest. ν
- WIMPs
- magnetic monopoles,
  strangelets, ...
- CR and muon physics
  (+ top array EAS)
- oceanology, limnology, glaciology
- Earth tomography

Mannheim & Learned, 2000

Diffuse Fluxes: Predictions and Limits



1 pp core AGN (Nellen)
2 pγ core AGN Stecker & Salomon)
3 pγ „maximum model“ (Mannheim et al.)
4 pγ blazar jets (Mannh)
5 pγ AGN (Rachen & Biermann)
6 pp AGN (Mannheim)
7 GRB (Waxman & Bahcall)
8 TD (Sigl)

▼ Frejus
▽ Fly´s Eye

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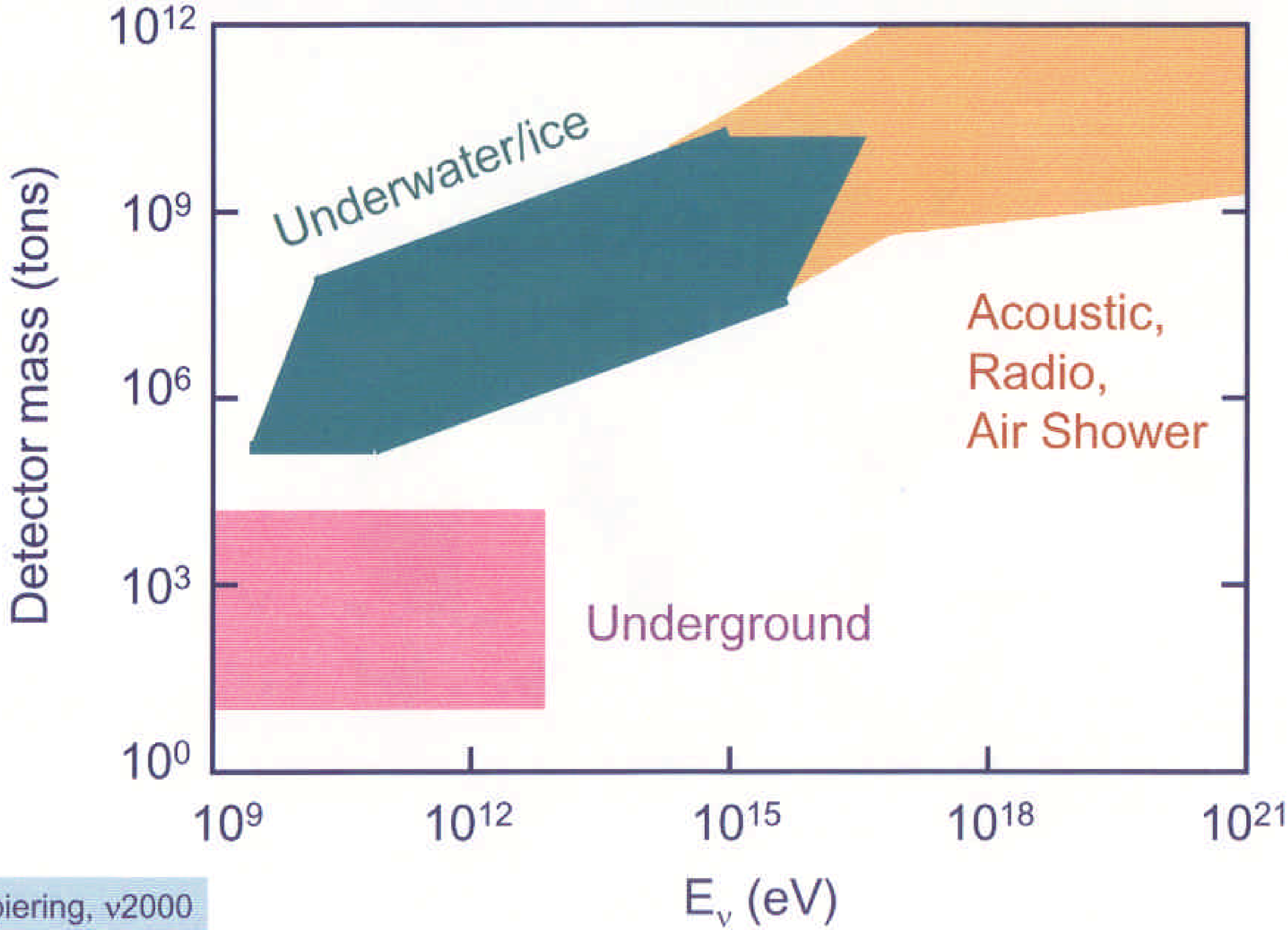
From 10^3 to 10^9 to 10^{12} tons



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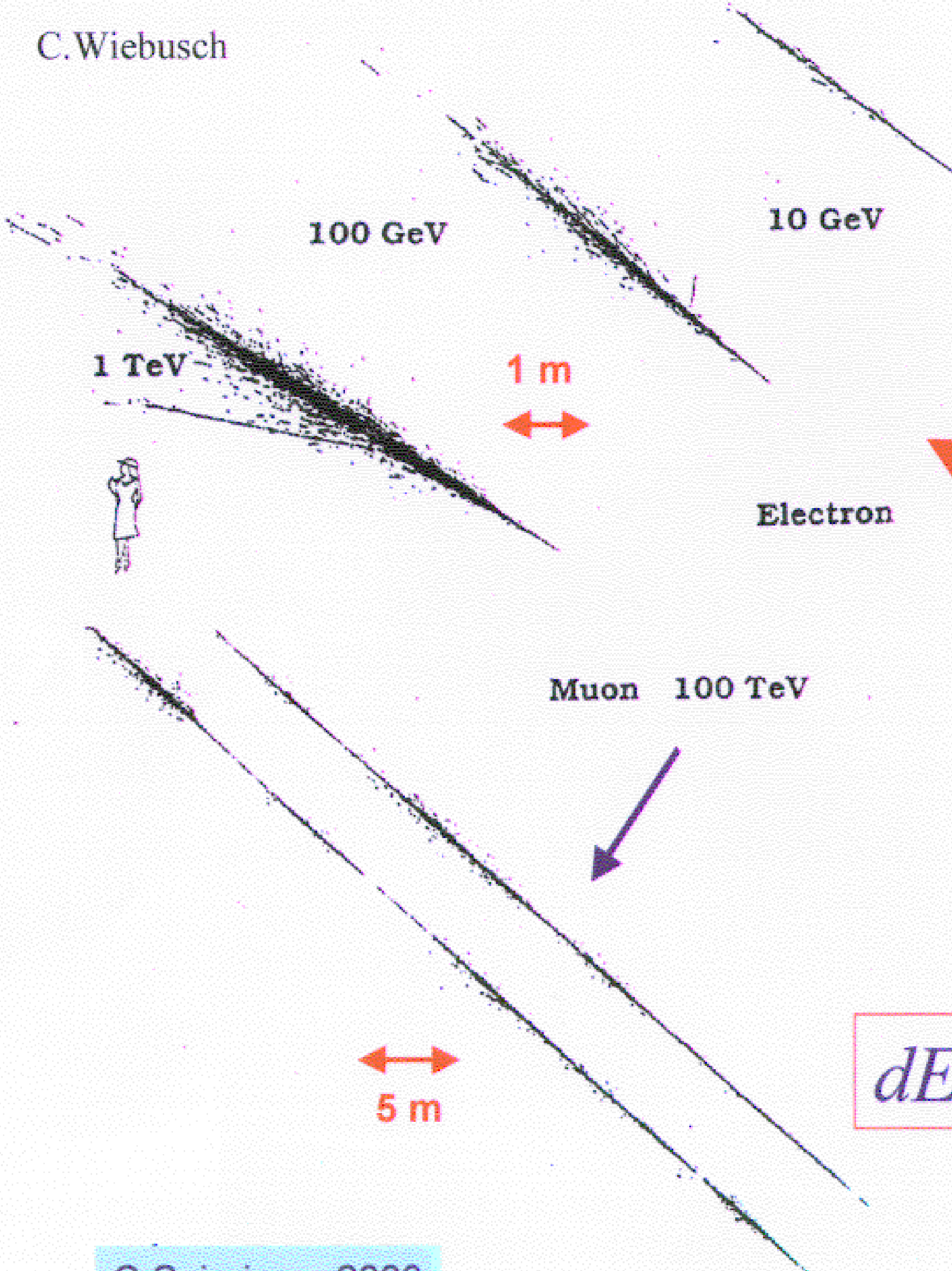
Tracks and Cascades

C.Wiebusch



$$L_{shower} \propto \ln E_e$$

$$dE/dx \propto a + b \cdot E_\mu$$

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Underwater/Ice Detectors

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Underwater/Ice (optical)

UMAND

Baikal NT200

AMANDA → IceCube

Mediterranean

NESTOR

ANTARES

NEMO

} km3

Spiering, ν2000

Site Choice for Underwater/ice Telescopes

geographic location — **be complementary!**

depth — ocean $\uparrow$

absorption — Amanda $\uparrow$

infrastructure — Amanda $\uparrow$

scattering — water $\uparrow$

transport — oceans $\uparrow$

homogenity — water $\uparrow$

deployment — Amanda $\uparrow$ (?)

external noise — Amanda $\uparrow$

reliability (repair) — ?

rigidity — Amanda $\uparrow$

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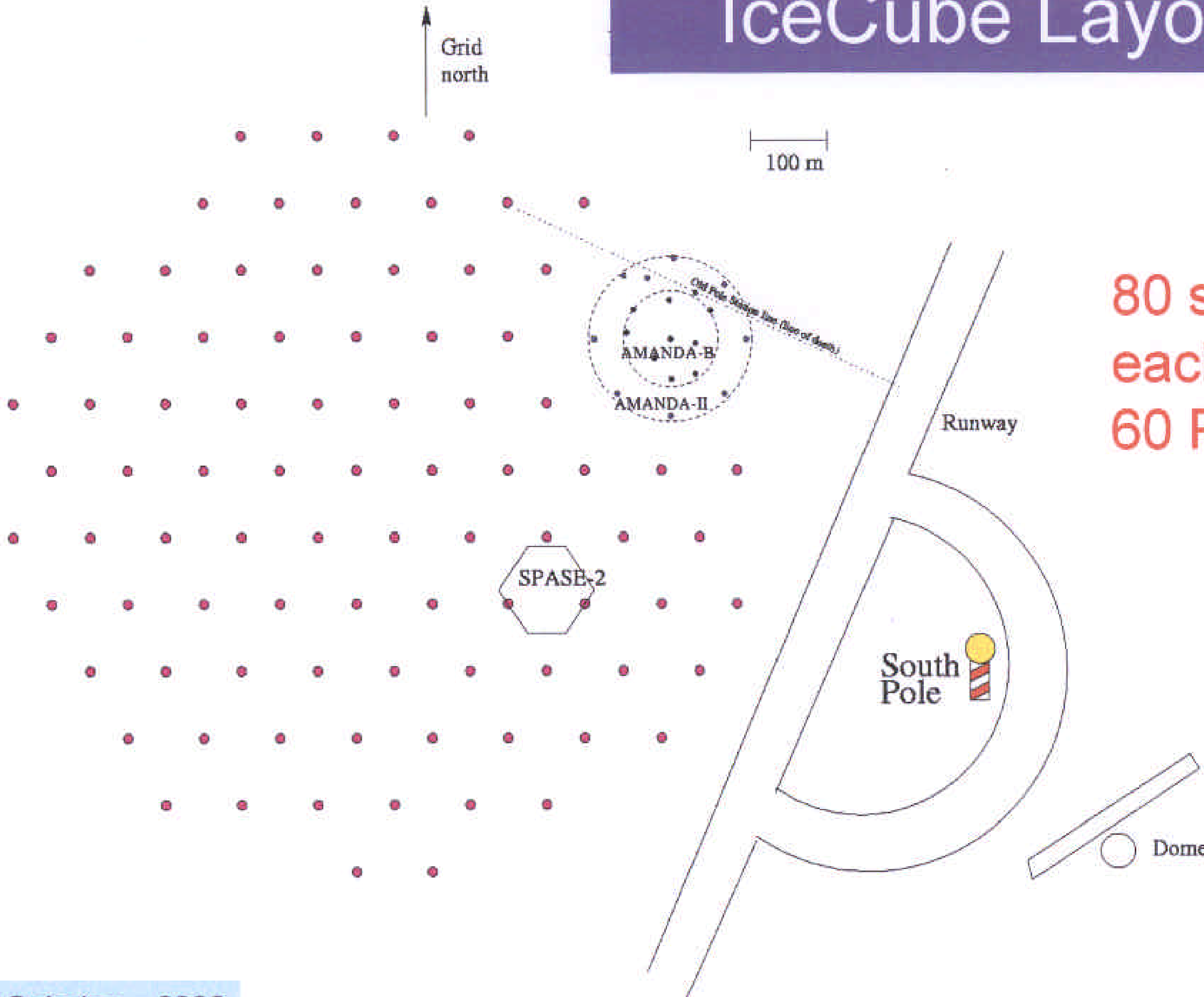
IceCube:

Example for KM3

IceCube Layout



80 strings,
each with
60 PMTs

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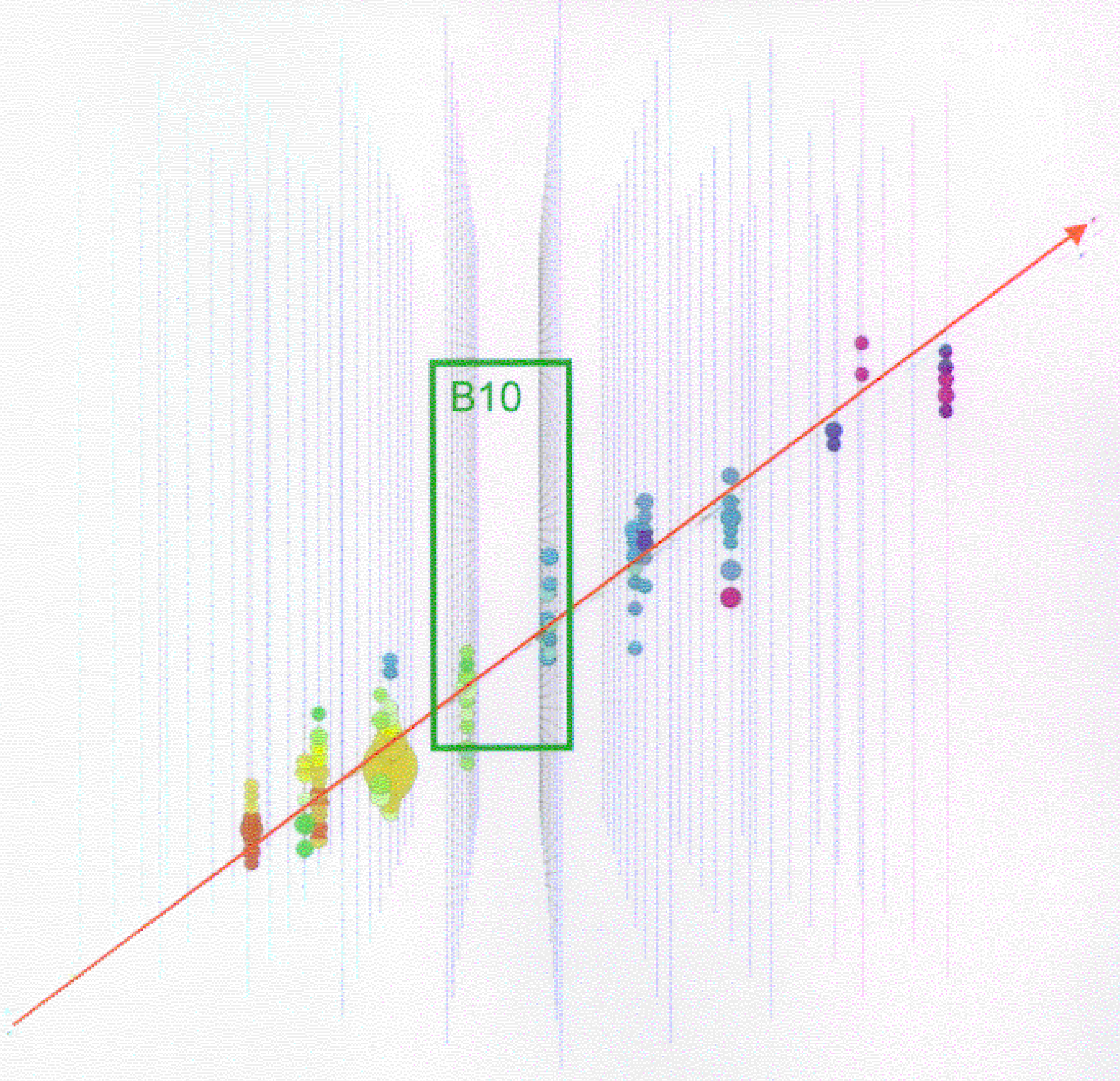
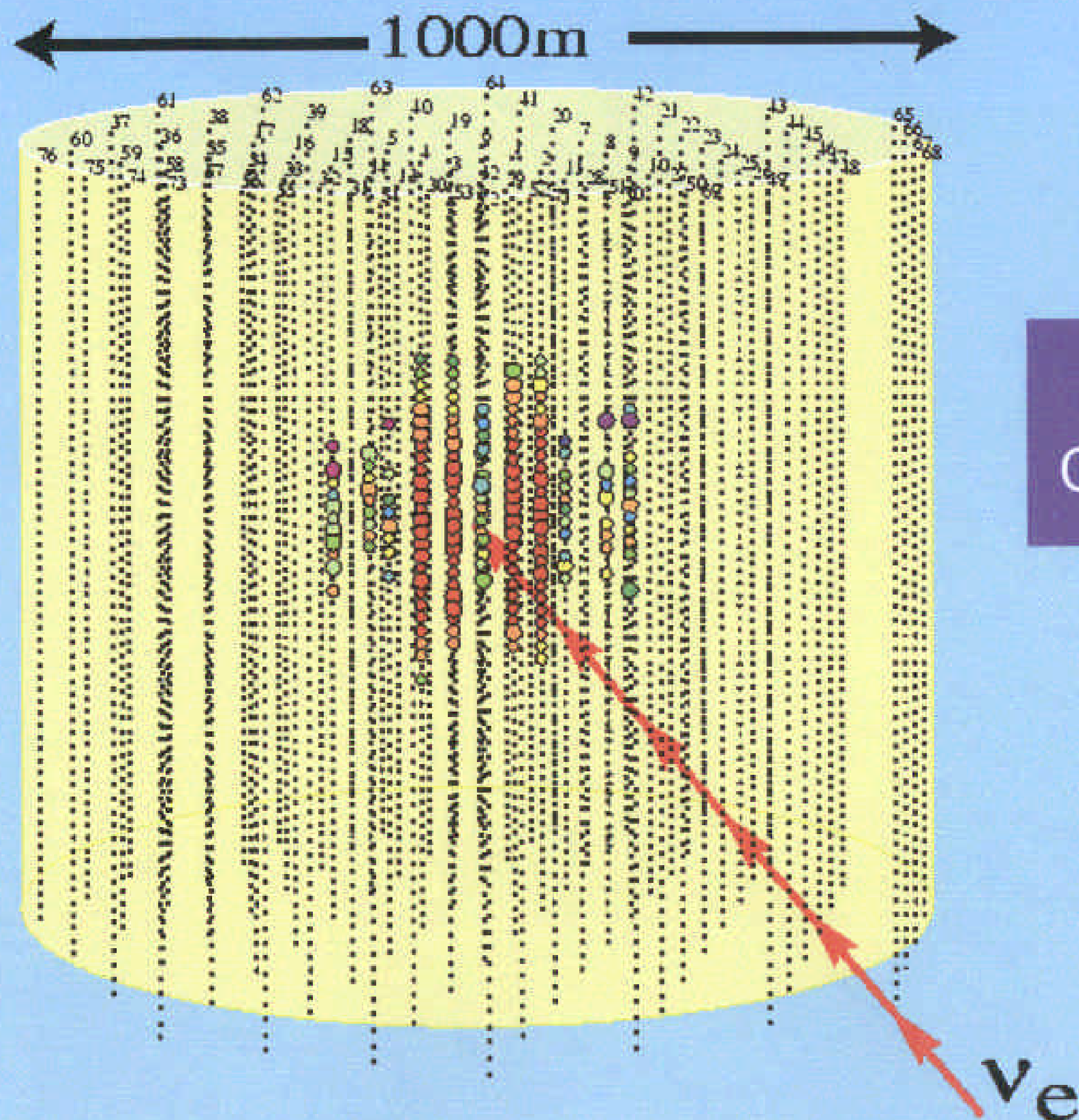
Muon Track in IceCube

Amanda B10:
~ 300 PMs
200 atm. ν´s
in 132 days

IceCube:
~ 5000 PMs
250 atm. ν´s
per day



IceCube



PeV ν_e Cascade

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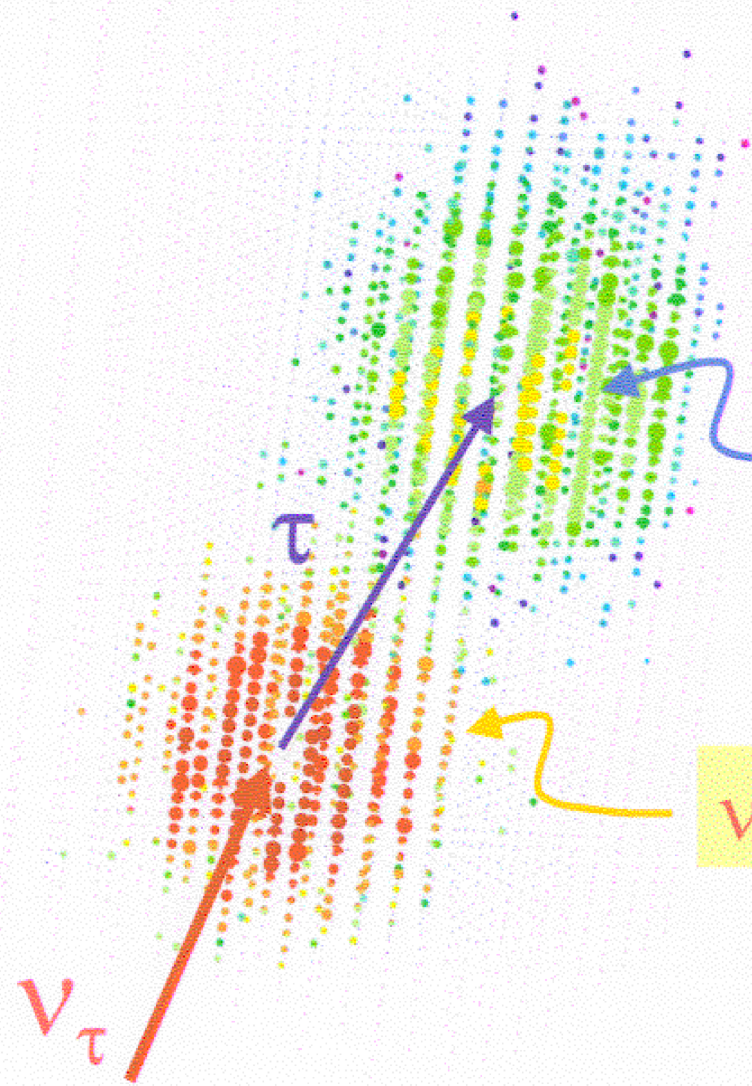
IceCube
Double Bang Event



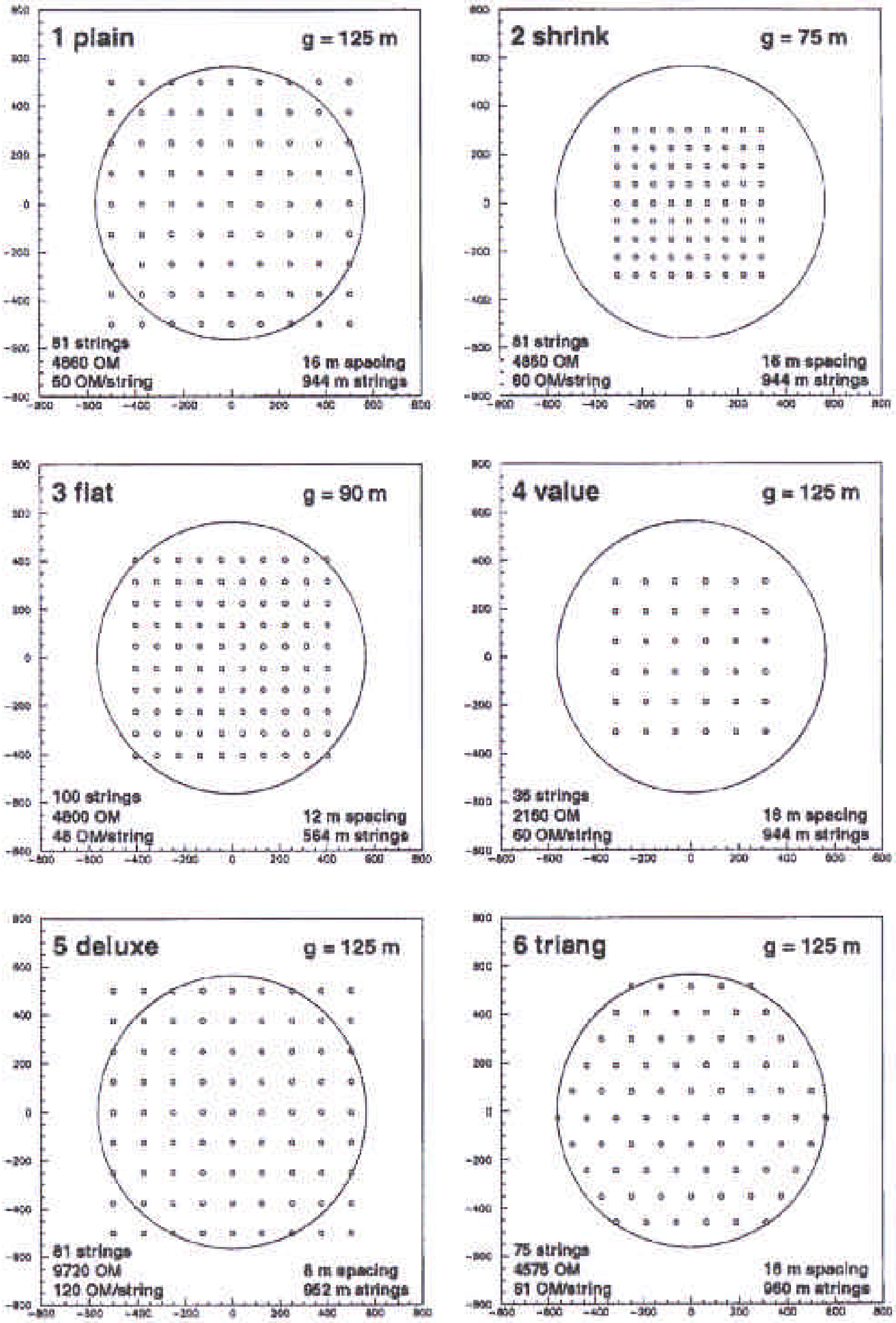
$\tau \rightarrow \text{hadrons} + \nu_\tau$

$\nu_\tau + N \rightarrow \tau + ...$

multi-PeV regime

piering, ν2000

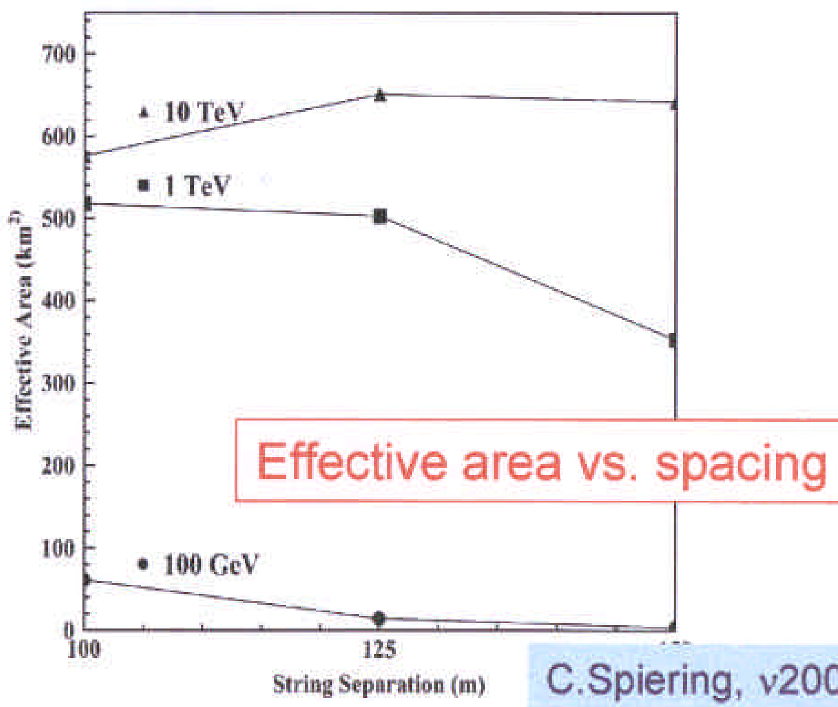
Configurations



1. standard
2. shrinked
3. flat
4. 50% OMs
5. 200% OMs
6. Triangular

plus „nested“ arrays

standard: 81 strings, 944 m long
60 PMs/string 4860 PMs



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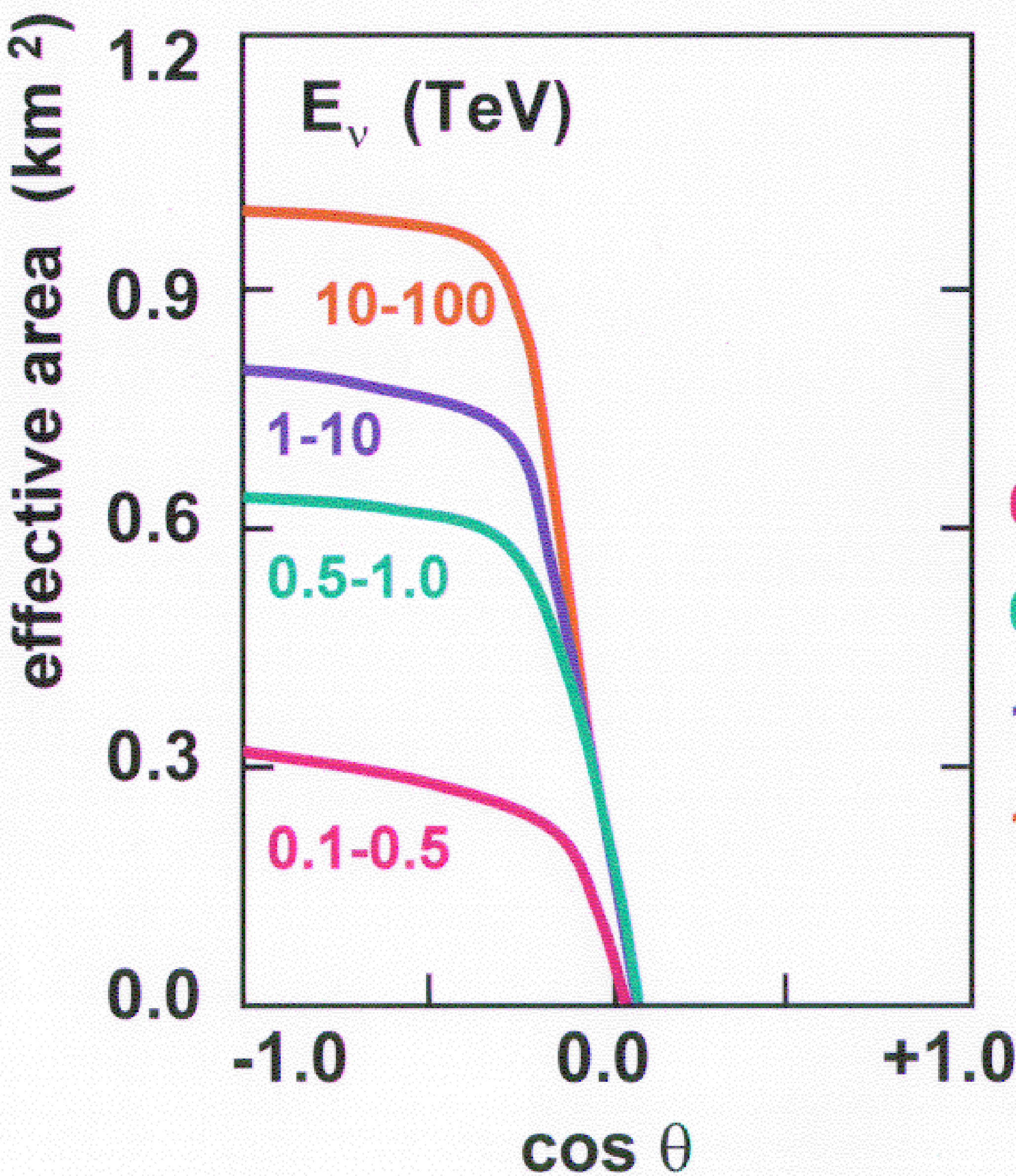
Leuthold, Madsen, 2000

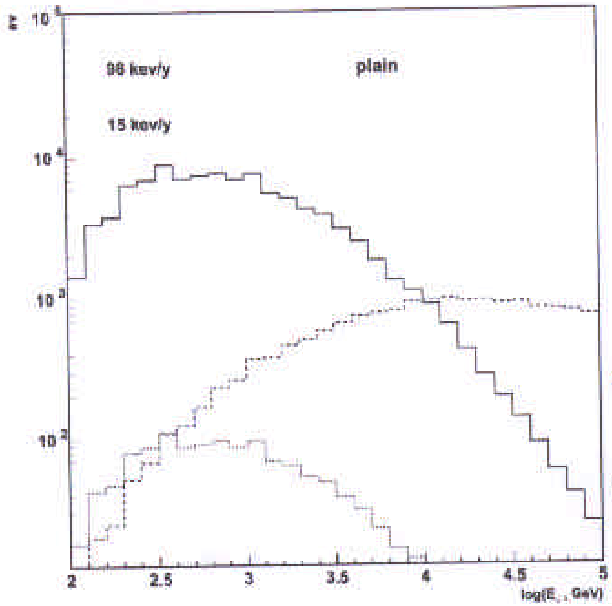
IceCube (plain): Effective area & events/year



	atm.ν	AGN*
0.1- 0.5	35 000	300
0.5- 1.0	22 000	600
1-10	37 000	6100
10-100	3 000	8200

* assuming 10^{-6} E^{-2}

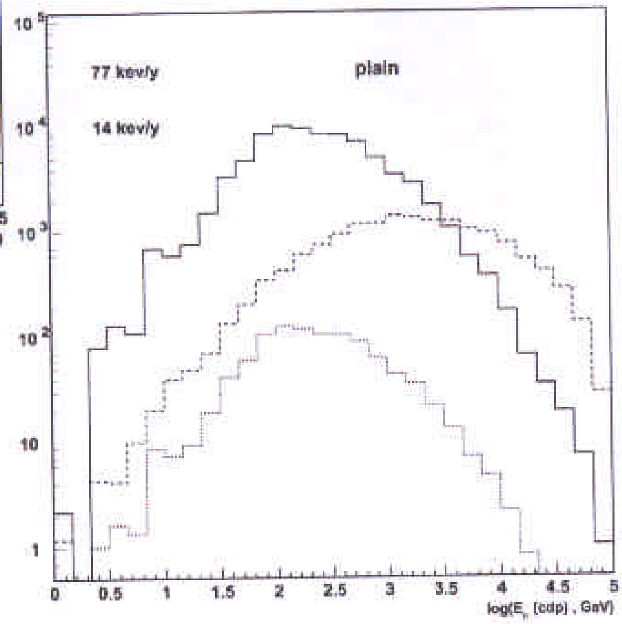
Energy Spectra in IceCube



neutrinos

M.Leuthold, 1999

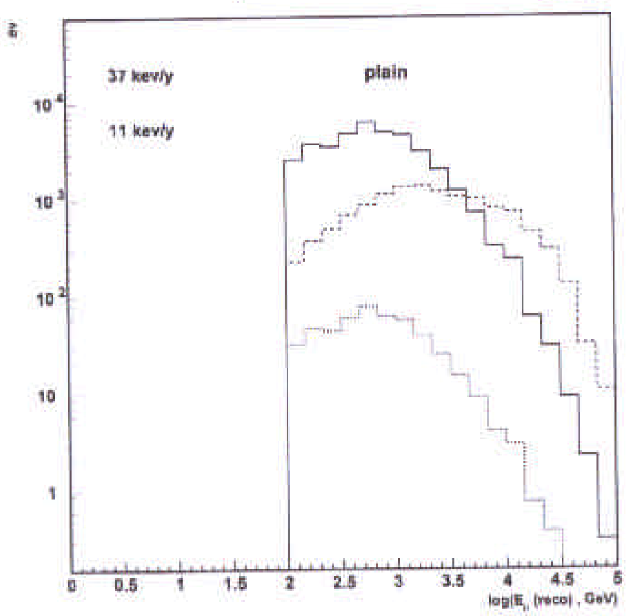
Muons (true energy)



Much better separation in *E* for subsample of events with vertex in IceCube !

Muon energy resolution here: $\sigma(\ln E) \sim 0.4$ expect´d: $\sigma(\ln E) \sim 0.25$

Muons (reconst. energy)



upper curve:
atm. ν over 2π

middle: AGN E^{-2} 10^{-6}

lower curve:
atm.ν over $2\pi/100$ ← Assuming most of the „diffuse" signal coming from a few ten AGN

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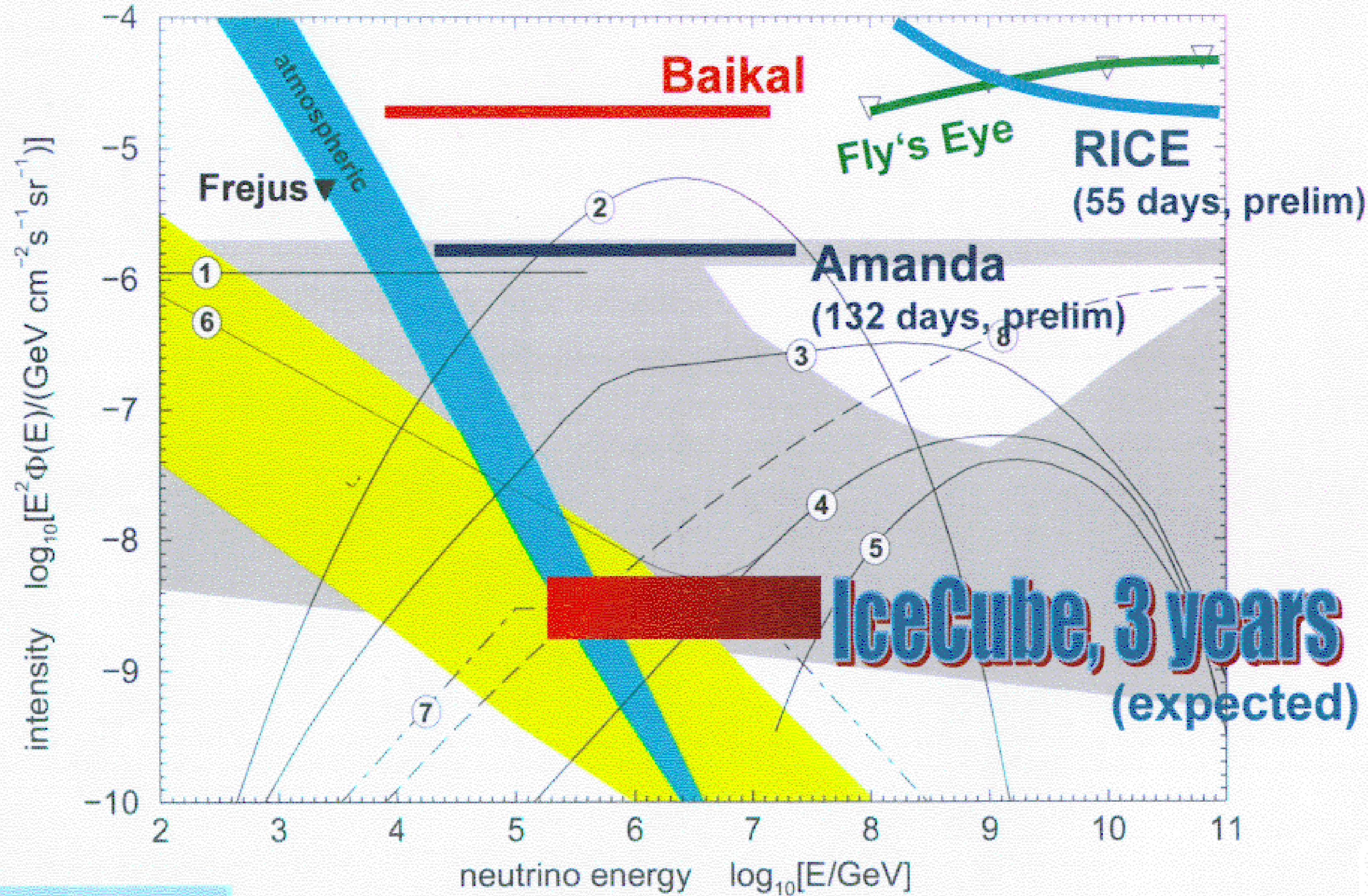
Diffuse Fluxes: New Limits



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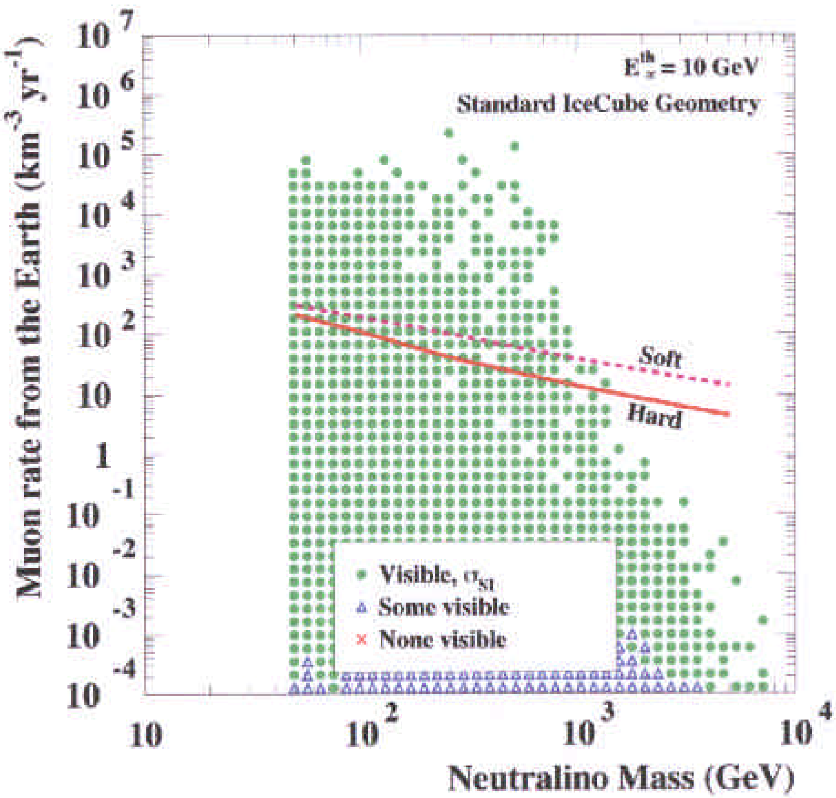
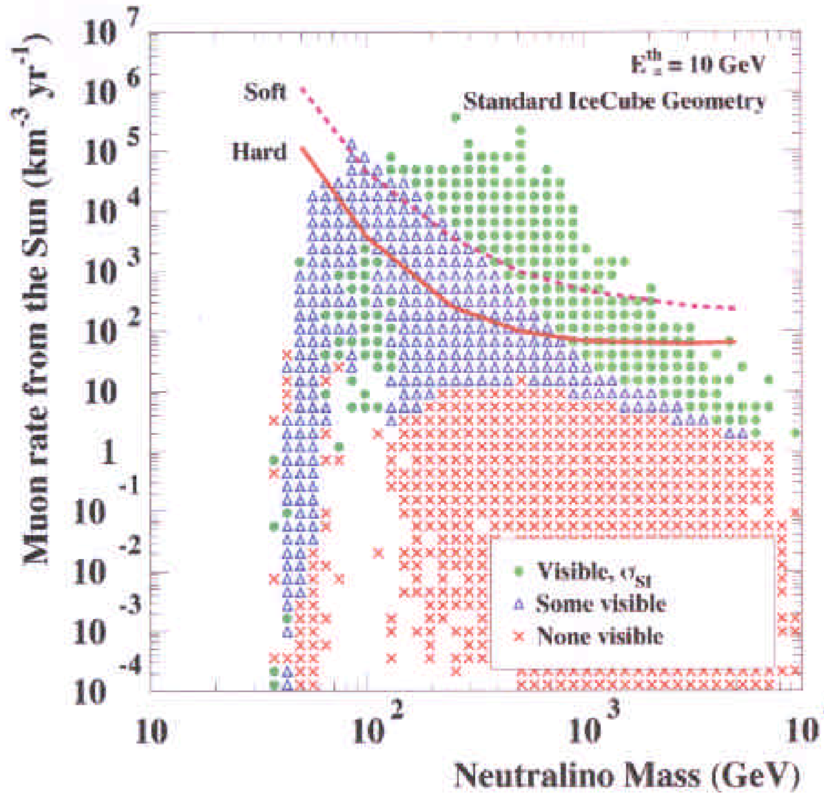
J.Edsjö, 2000

WIMP search with IceCube

Muon rates from WIMPs annihilating in the Earth (left) and in the Sun (right).

MSSM predictions. Lines correspond to IceCube limits. Colors indicate detectability by future direct detection experiments (CRESST, GENIUS)





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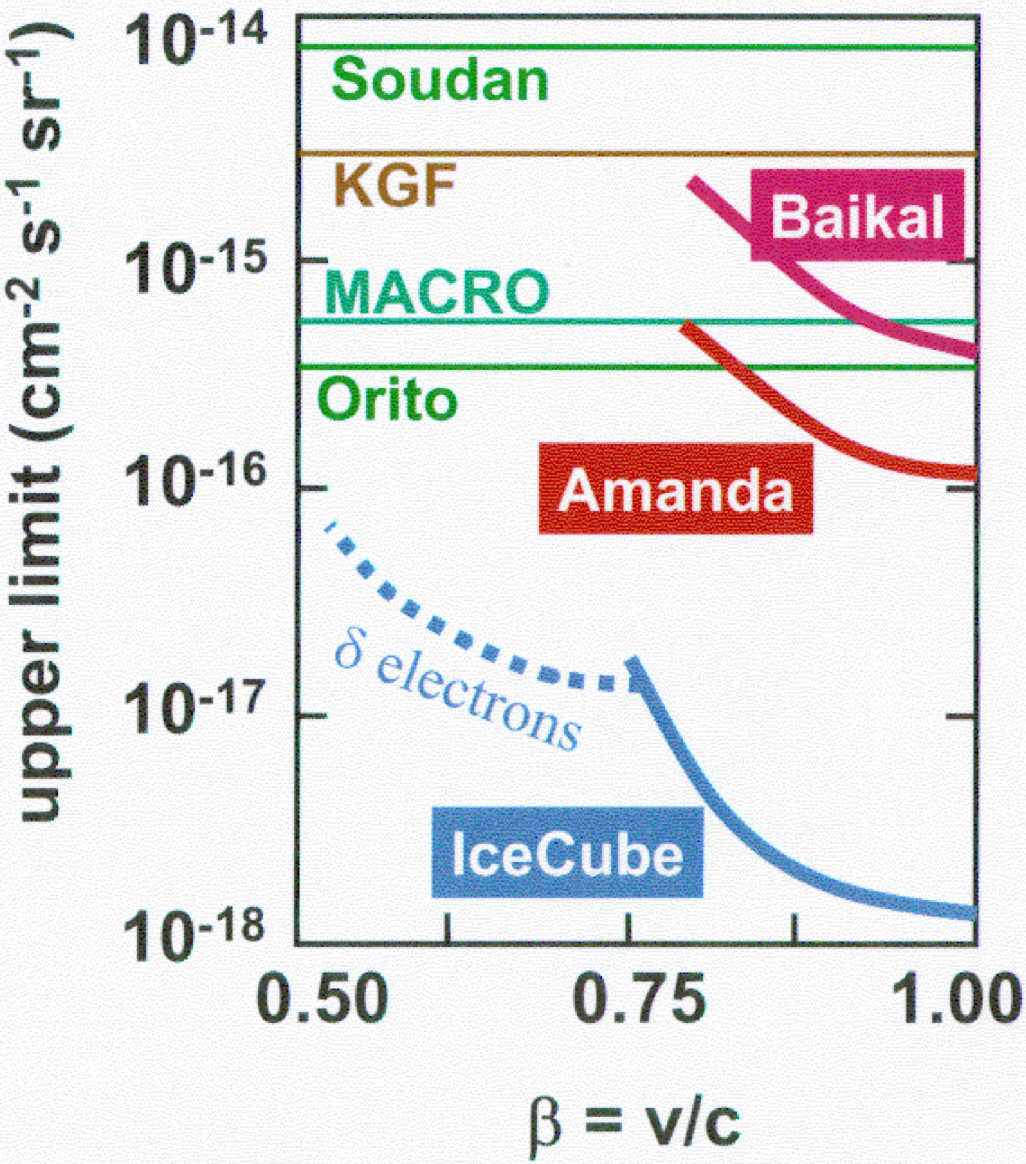
Relativistic Magnetic Monopoles



C - light output ∝ $n^2 \cdot (g/e)^2$

$n = 1.33$

$(g/e) = {}^{137}/_{2}$

≈ 8300

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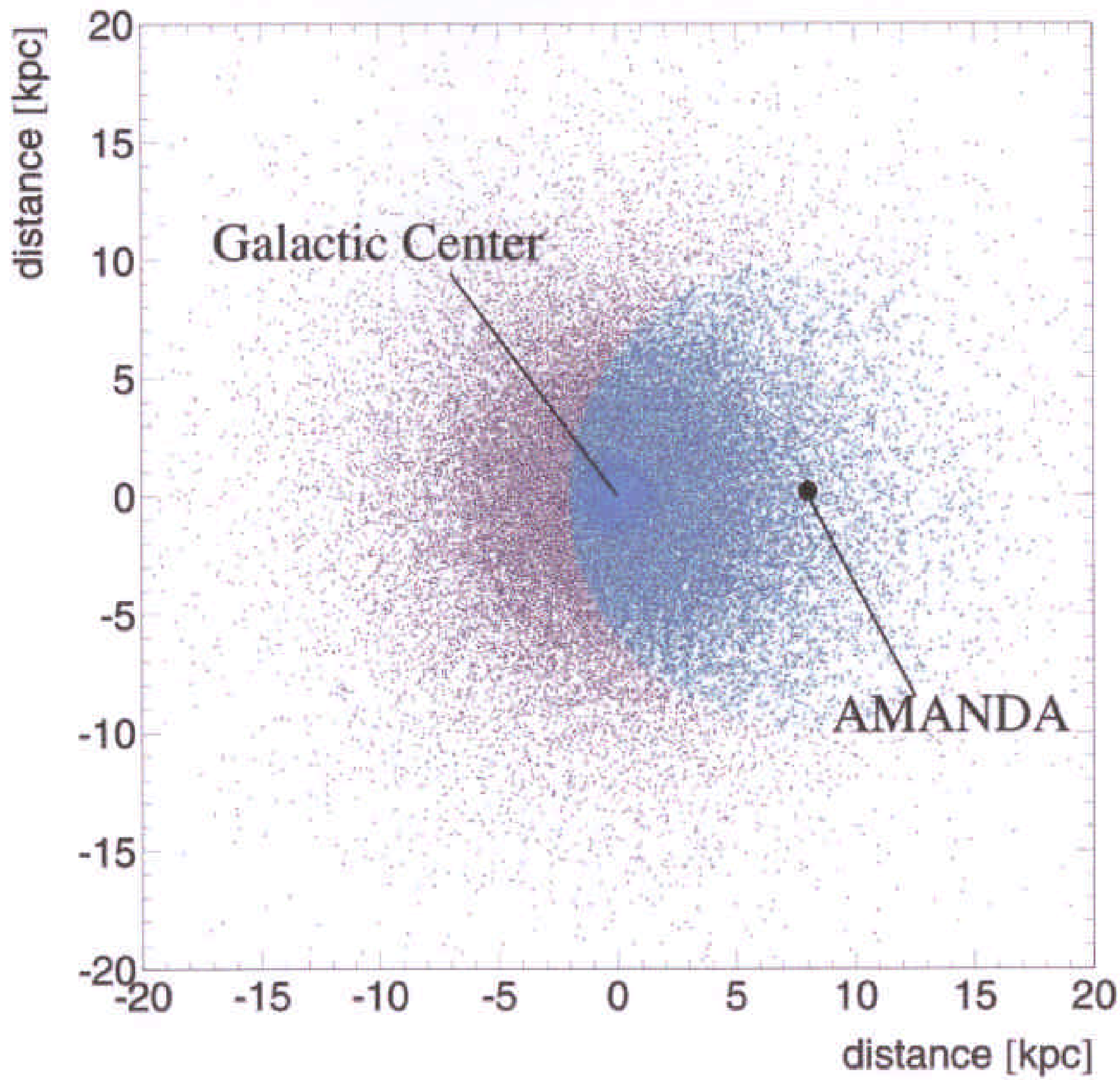
Supernova Monitor

Amanda B10 has monitored 60% of the Galaxy with 90% detection efficiency for a SN1987A type supernova.

IceCube will monitor the full Galaxy.

Amanda is going to join SNEWS in 2001.



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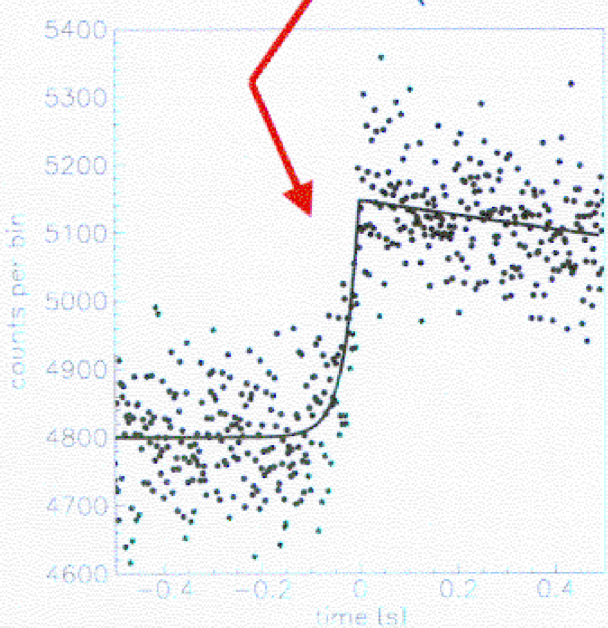
Koepcke et al, 2000

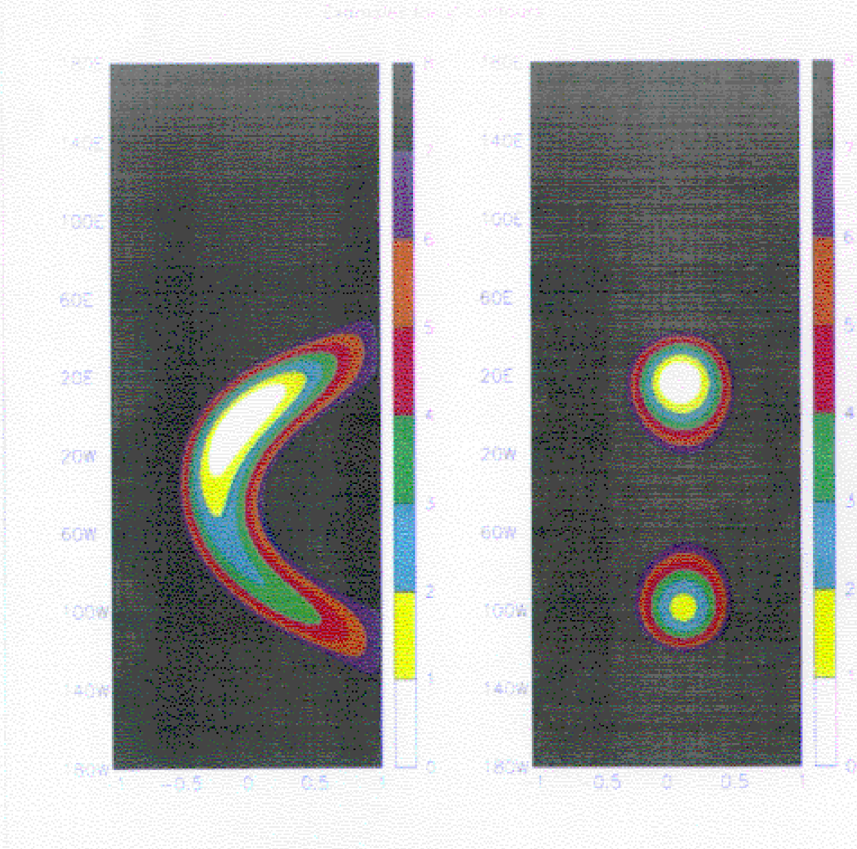
Supernova Triangulation ?

Record increase in average counting rate of all PMs with msec accuracy.

Δt (Amanda-II) = 14 msec
Δt (IceCube) = 3 msec

(model dependent!)





χ^2 contours of reconstructed SN direction.

Left: Amanda-II. Right: IceCube
(+ Super-K + SNO)

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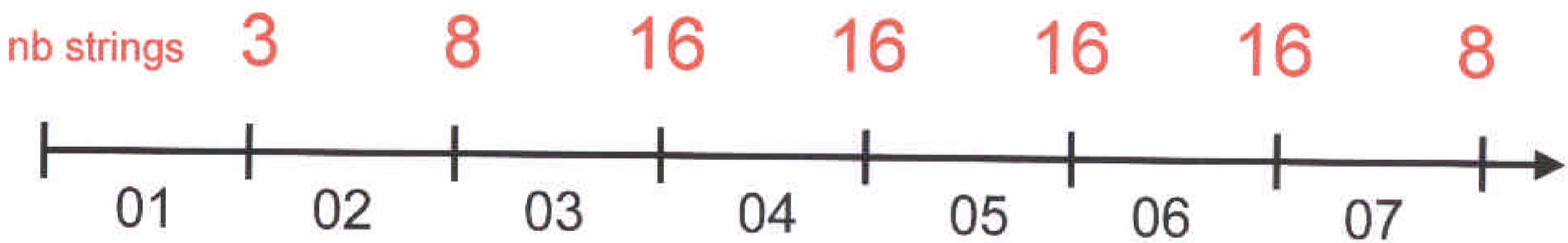
IceCube Time Schedule

(Sagenap March 00)

Technology verification
(detector and new drill)
+ AMANDAII upgrade



Completion,
then 7-10 years data taking
with full array

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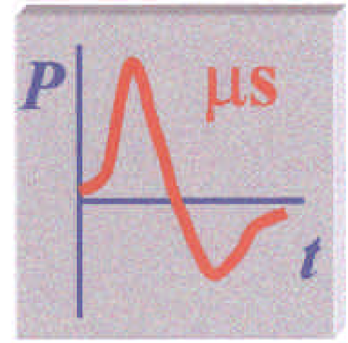
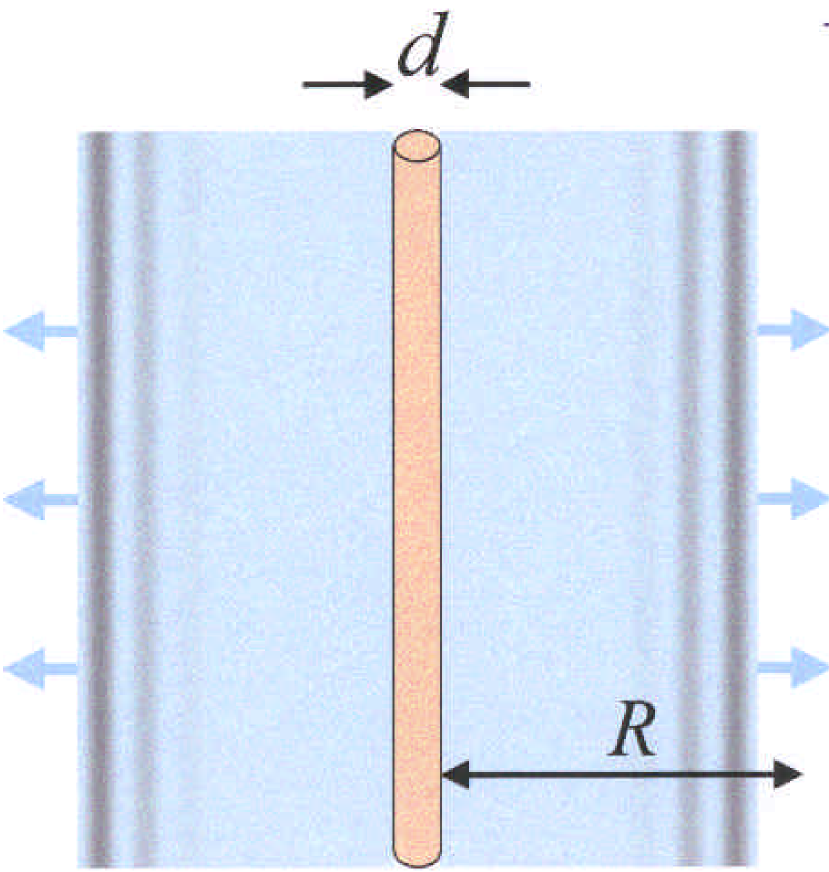
Acoustic and Radio Detection

Askaryan (1957)
Bowen (1977)
Learned (1979)

Acoustic Detection

Particle cascade → ionization
→ heat
→ pressure wave





$$P \propto \frac{K \cdot E}{C \cdot R \cdot d^2}$$

P pressure
K expansion coefficient
C heat capacity
E cascade energy
d cascade diameter
R distance

Acoustic Detection (2)

Attenuation length of sea water at 15-30 kHz:
a few km

light: a few tens of meters

given a large initial signal, huge detection volumes can be achieved.

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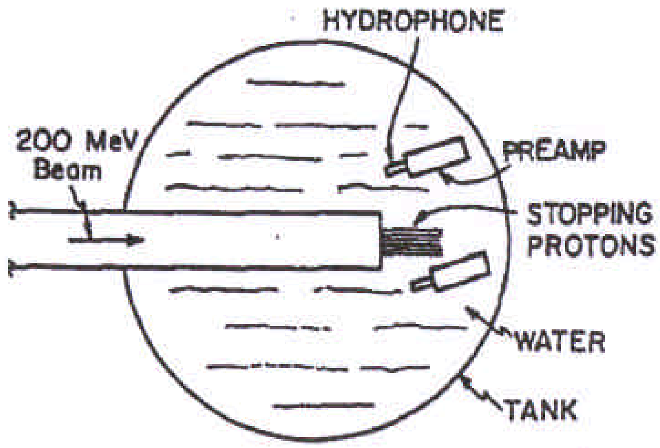
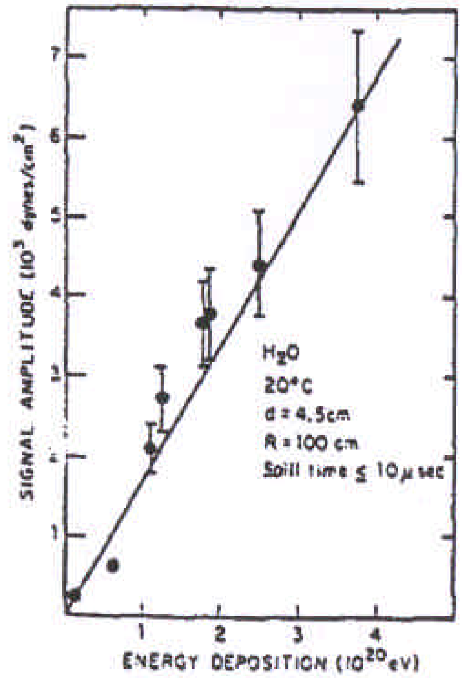
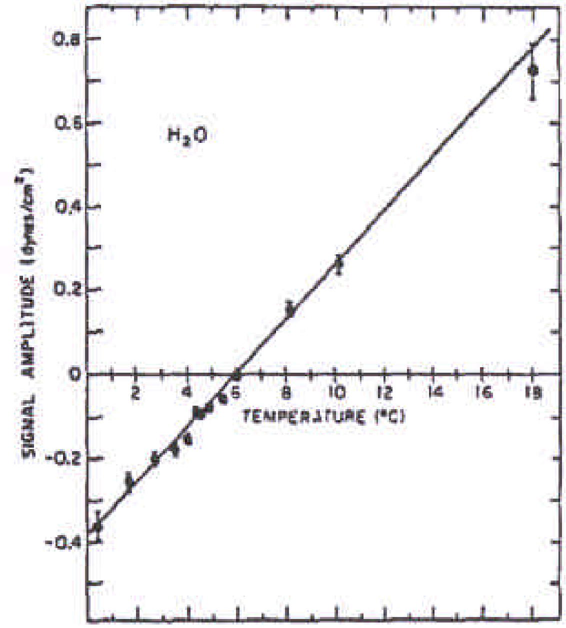
Acoustic Detection (3)

Sulak et al., 1979: Experimental verification at BNL







200 MeV protons
∅ = 1cm
L = 30 cm

basically thermo-acoustic

→ largest signal in Mediterannean (14°C)

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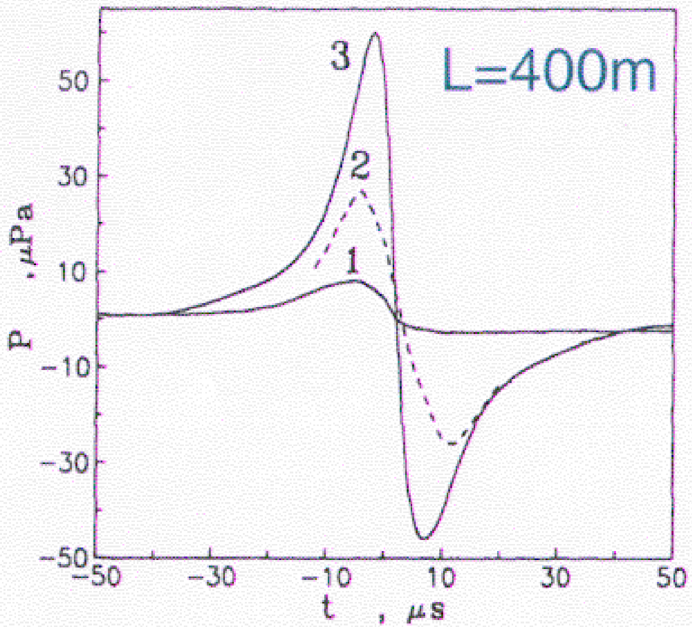
Acoustic Detection (4)

Mediterannean, 4 km depth,
14 °C (Butkevitch et al, 1995)

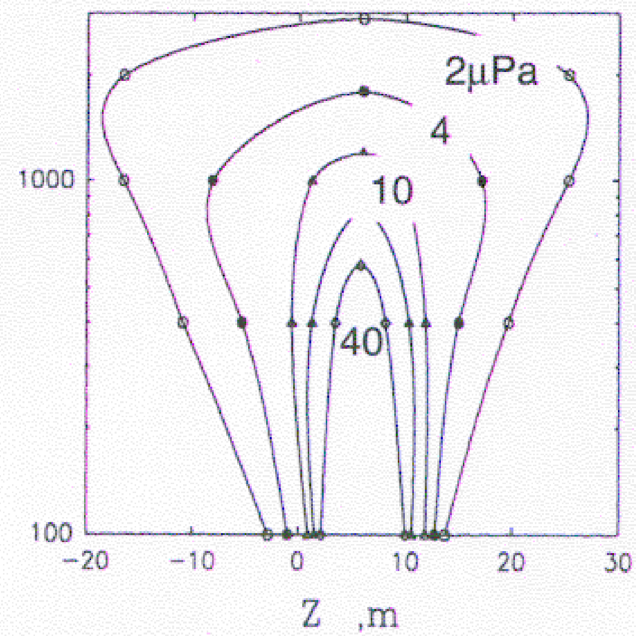


1 Learned
2 Askaryan et al.
3 Dedenko et al.

f = 5-50 kHz

60 μPa ≈ sens.(ear)

10 PeV cascade



1991/92 noise measurements

≥ 12 μPa/√Hz
at 15-30 kHz

↓

background limitation

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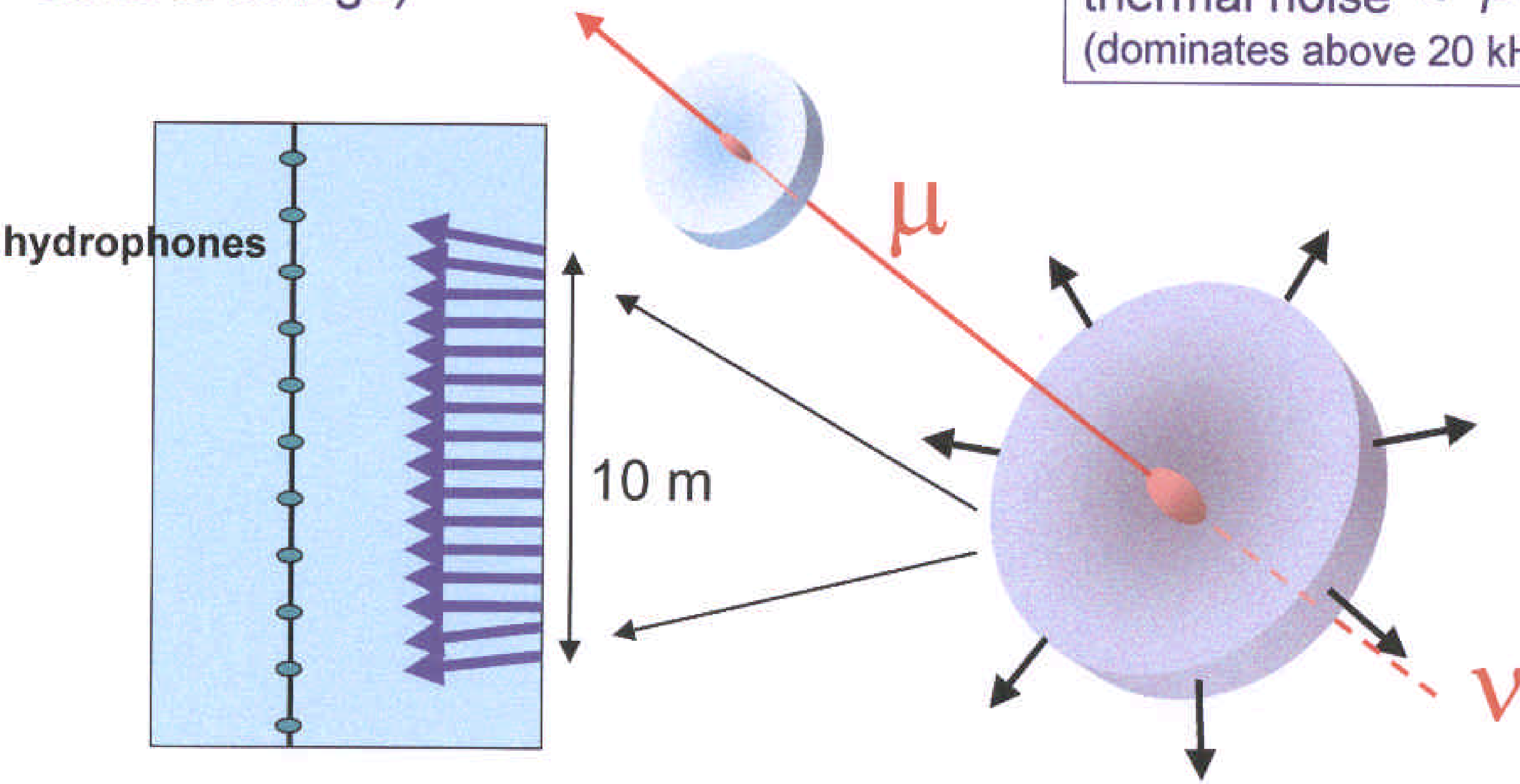
Acoustic Detection (5)

Improve S/N : many hydrophones (close to each other as well as at several strings)

surface noise ~ $1/f$
thermal noise ~ f^2
(dominates above 20 kHz)



Acoustic Detection (6)

SADCO Mediterannean, NESTOR site
3 strings, each with 128 hydrophones along 100m
strings 100-200 apart
threshold 6 PeV over 10^9 m^3

Kamchatka existing sonar array for submarine detection
2400 hydrophones
f a few hundred Hz
→ small signals
→ large attenuation length
→ hundreds of km^3 above 10^{20} eV ?

Antarctic Ice acoustic vs. radio: radio wins !

Baikal first signals from air showers?

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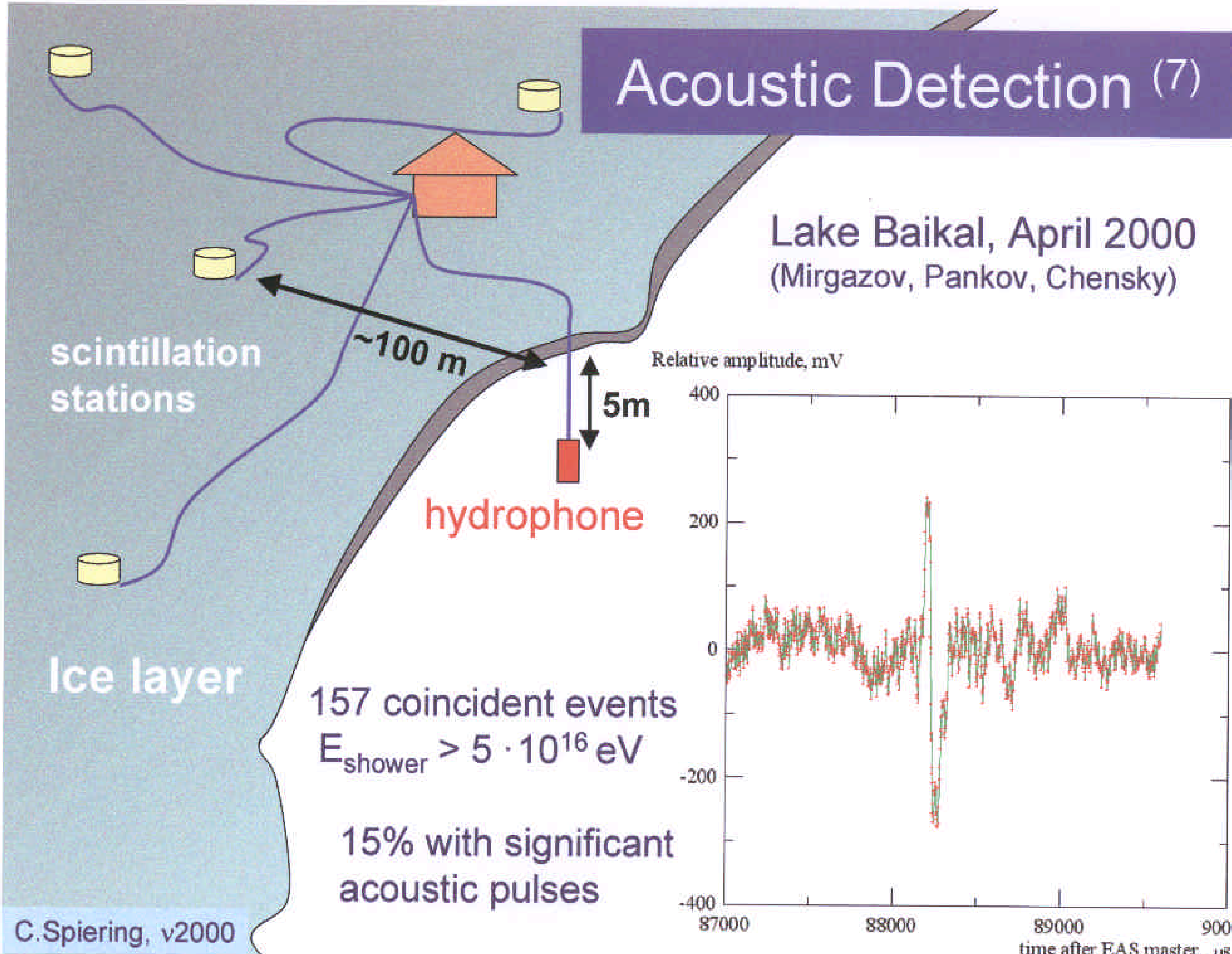
Acoustic Detection (7)
Lake Baikal, April 2000
(Mirgazov, Pankov, Chensky)
scintillation stations
~100 m
5m
hydrophone
Ice layer
157 coincident events
$E_{shower} > 5 \cdot 10^{16}$ eV
15% with significant acoustic pulses
Relative amplitude, mV
400
200
0
-200
-400
87000
88000
89000
90000
time after EAS master, μs
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karyan

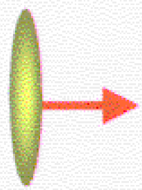
Radio Detection of Electro-Magnetic Cascades

$\nu_e + n \rightarrow p + e^+$

$e \rightarrow e^+ \, e^- \, \gamma \;\rightarrow \ldots$ cascade

negative charge is sweeped into developing shower, which acquires a negative net charge $Q_{net} \sim 0.25\, E_{cascade}$ (GeV).

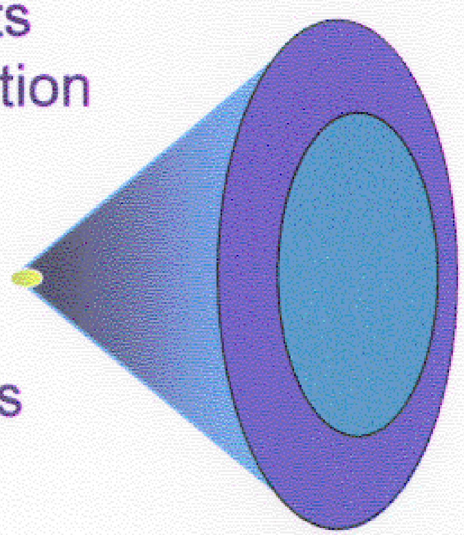
- relativist. pancake
  ~ 1cm thick, ∅ ~10cm

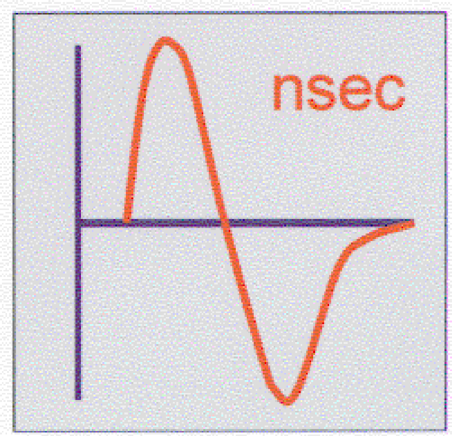


⇒ for λ >> 10 cm (radio)
coherence

⇒ C-signal ~ E^2

- each particle emits Cherenkov radiation
- C signal is resultant of overlapping Cherenkov cones





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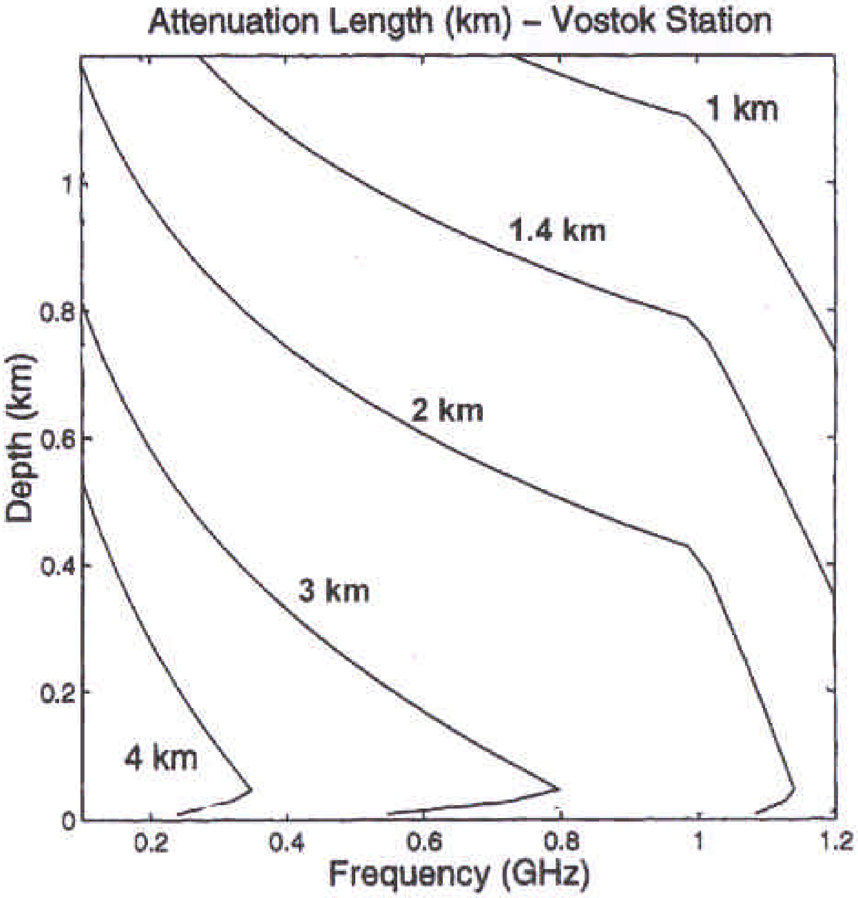
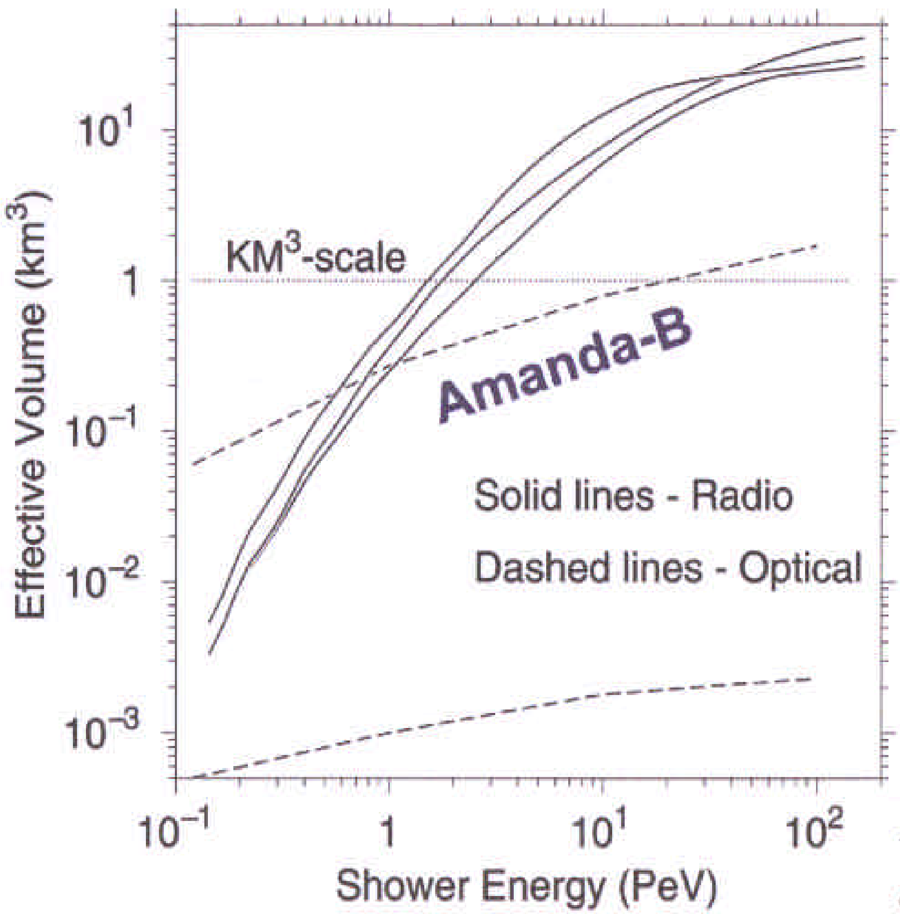
Radio Detection in Antarctic Ice

Large attenuation length results in large effective volume



Price, Frichter (96): radio wins for > 1 PeV



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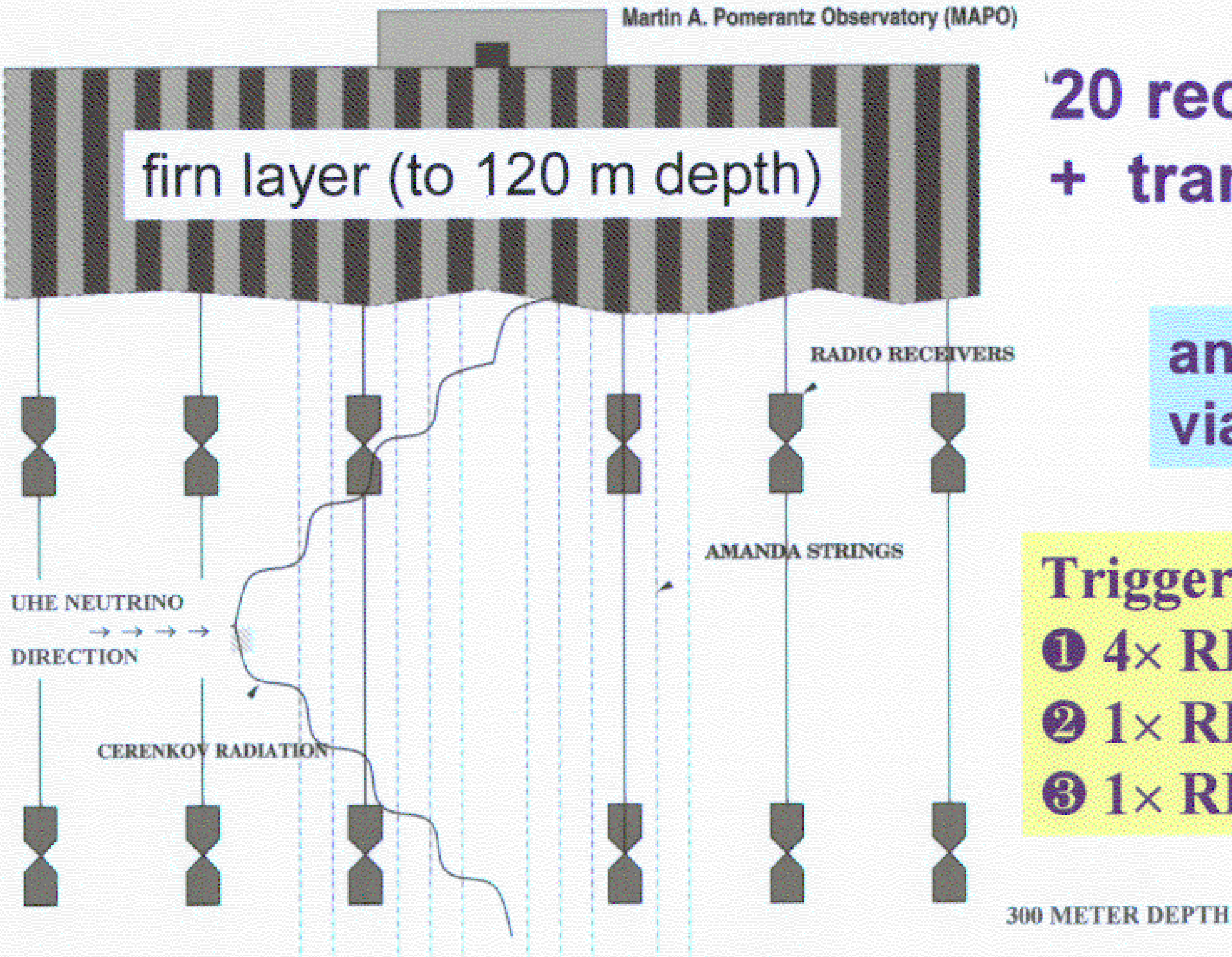
RICE

Radio Ice Cherenkov Experiment [(1)]



20 receivers
+ transmitters

analog signal via coax cable

Triggers:

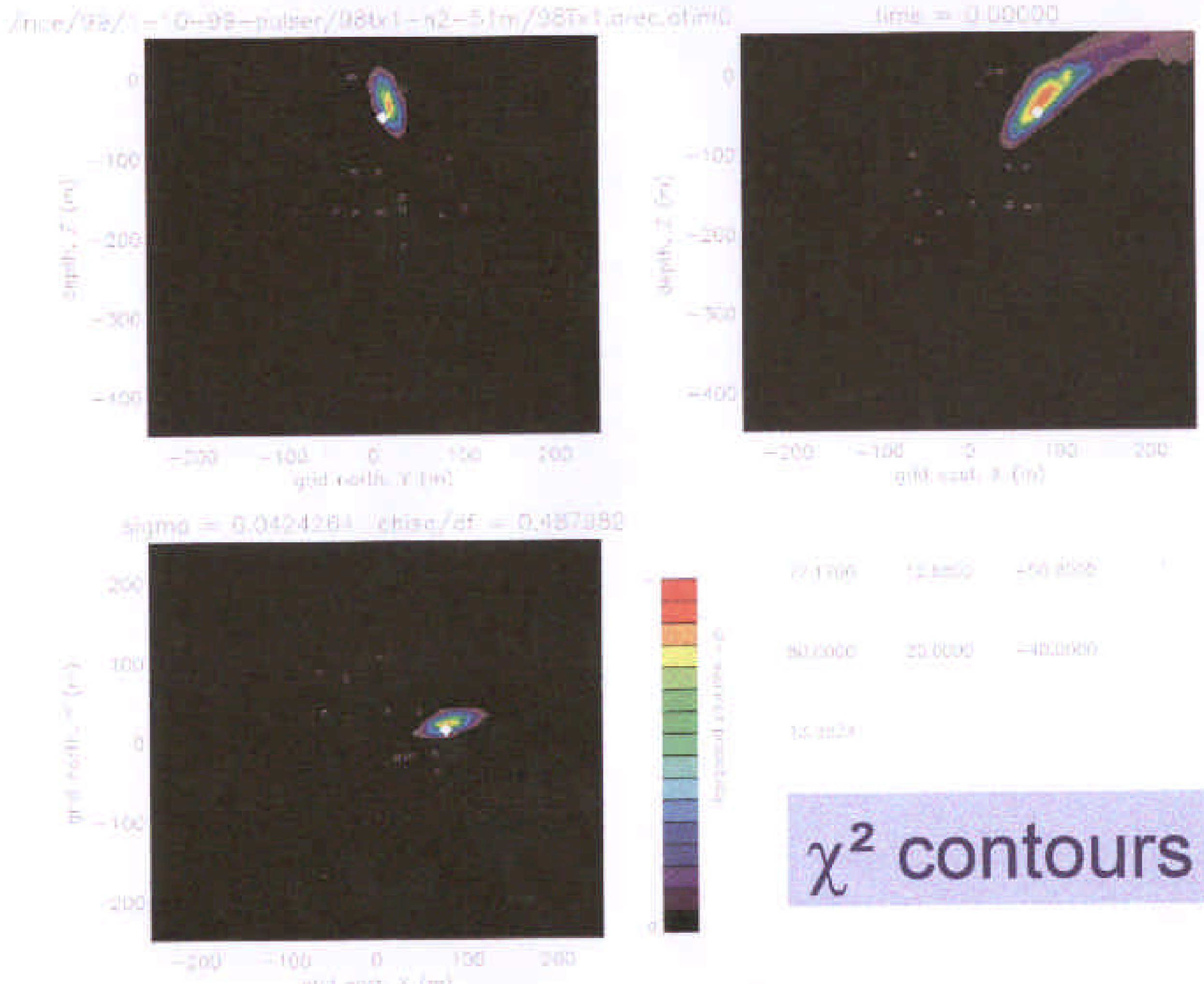
❶ 4× RICE ✓

❷ 1× RICE + Amanda A

❸ 1× RICE + SPASE

RICE

Radio Ice Cherenkov Experiment (3)



χ^2 contours

Calibration

Pulse from one of the transmitters (squares)

Reconstruction based on times ($\sigma \approx 10$m)

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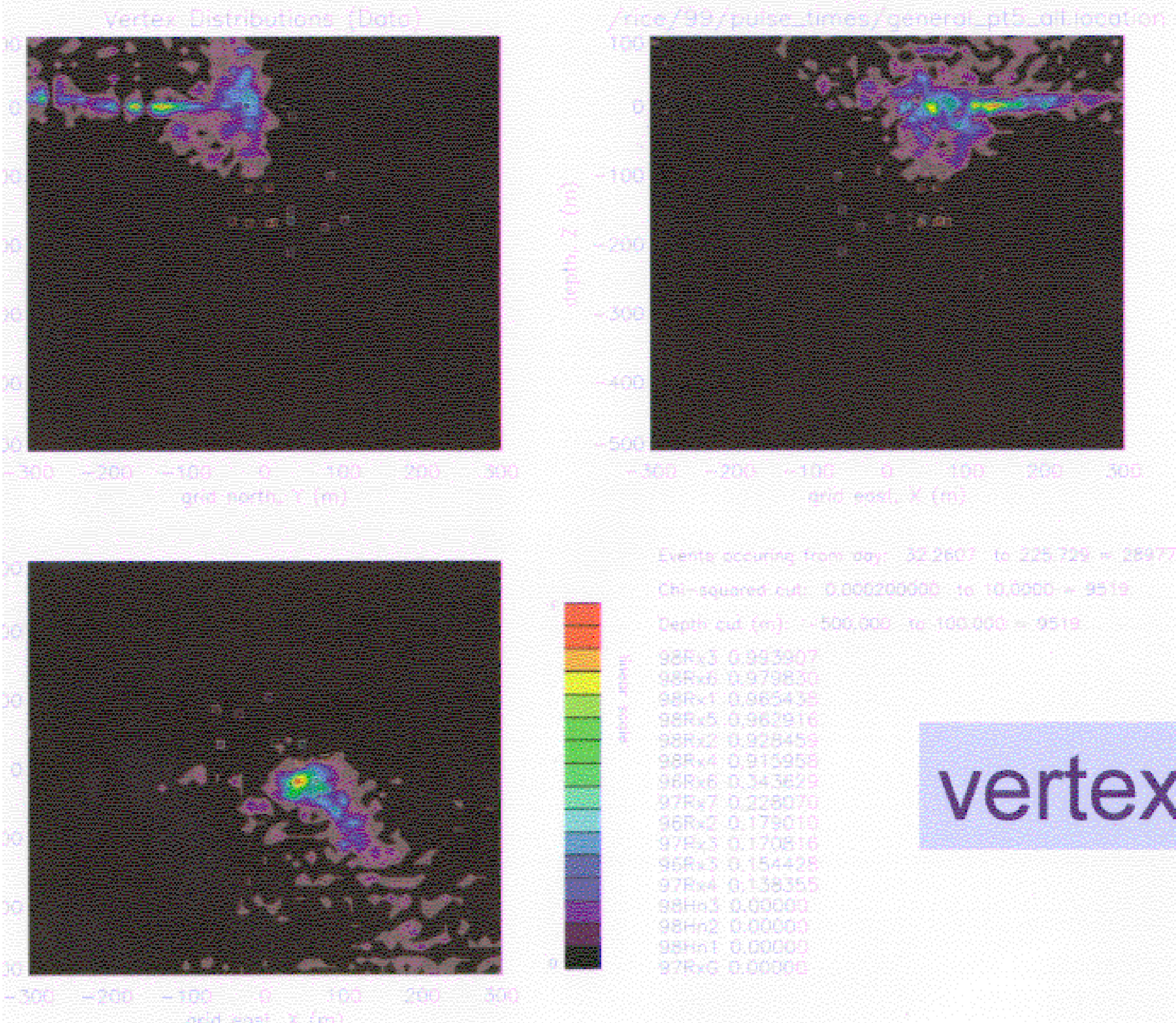
RICE
Radio Ice Cherenkov Experiment [3]



Surface Noise

vertex distribution

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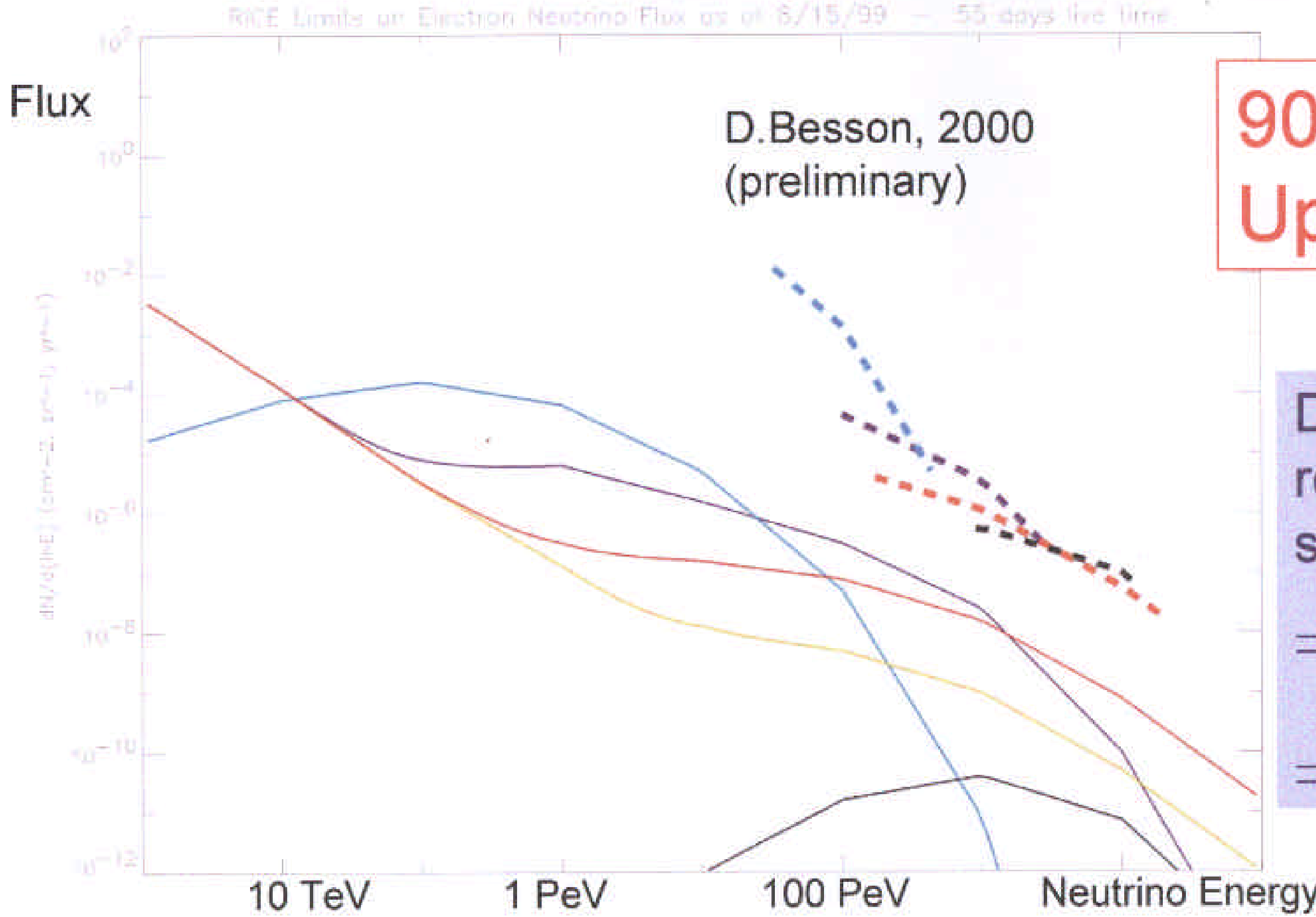
RICE

Radio Ice Cherenkov Experiment (4)



90% C.L. Upper Limits

Dramatically reduced sensitivity since

⇒ coax attenuates HF

⇒ surface noise

⇒ develop analog optical readout !

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5

Low and Super-high Energies

Megaton, low threshold

Tracking Detectors (sandwich Fe/Pb and scintill./gas detectors)

compact, medium mass but low effective area

Super-K × 20

- p-decay
- solar ν
- oscillations
- SN burst
- WIMP

> 7 MeV, 0.5 Mton

Baikal NT200×10 or dense array nested in large array

- WIMPs
- monopoles
- oscillations
- (extraterr. ν)

> 5 GeV, 1-5 Mton

Neutrino-Eye

- p-decay
- solar ν
- oscillations
- SN burst
- WIMP

> 10 MeV, 1 Mton

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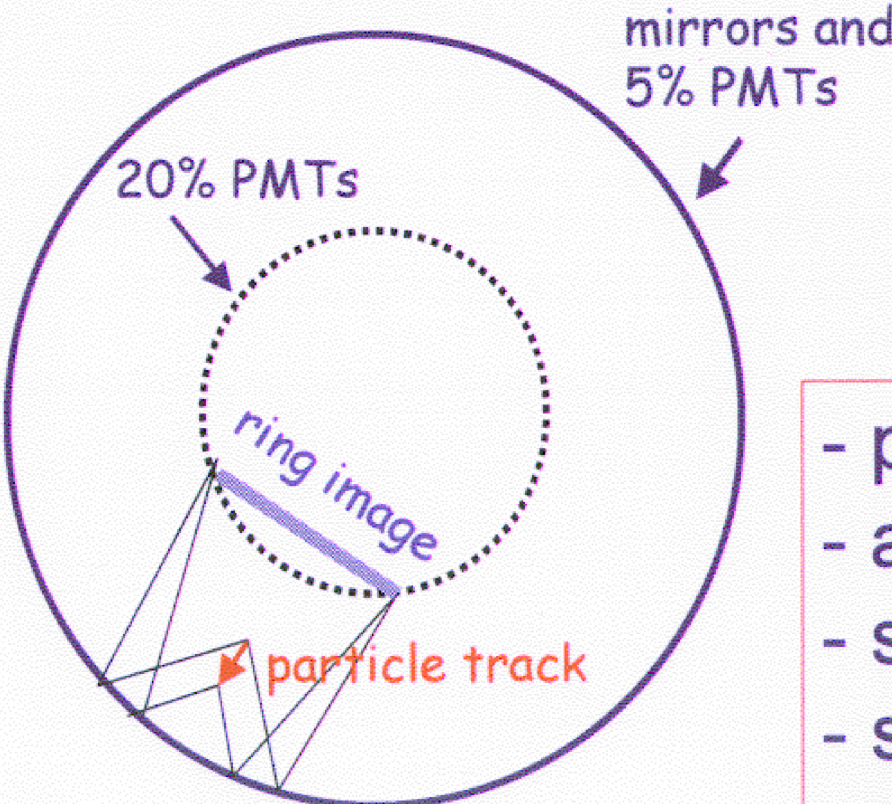
The „Neutrino-Eye"

(J.Learned 1998)

125 m diameter (1 Mt pure water)



Megaton, low threshold (2)

- deploy in Ocean
- movable (!)

- Aqua-Rich principle
- inner wall: HPD PMTs
- outer wall: 20" PMTs

- p-decay to 10^{35} years
- atm. ν oscillations
- solar ν to 5% every day
- supernova out to 2 Mpc
- extraterr. ν ?

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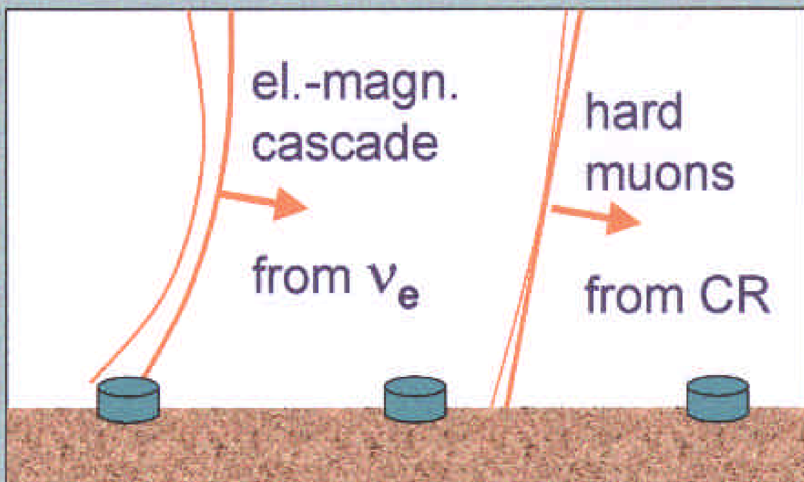
Superhigh Energies (1)

Horizontal showers in AUGER

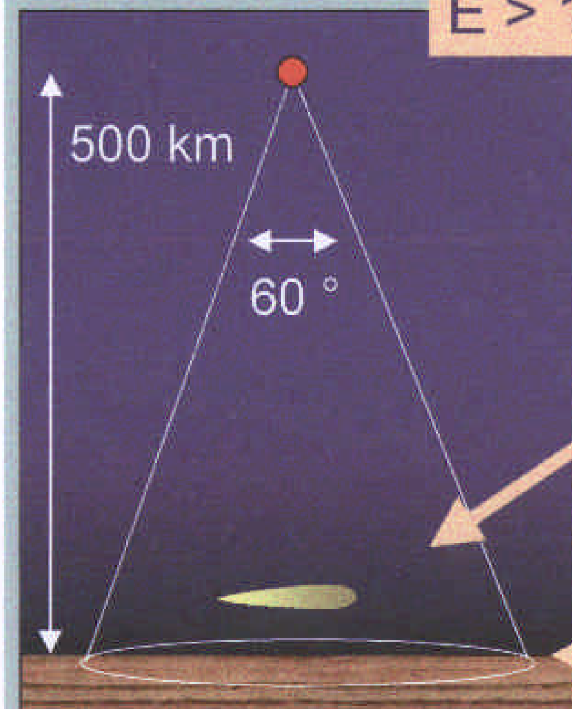


for $E \sim 10^{18} - 10^{20}$ eV:

mass = 1-20 Giga-tons
sensitivity ≈
$3 \cdot 10^{-7}$ GeV$\cdot$cm$^{-2}\cdot$s$^{-1}\cdot$sr^{-1}

Horizontal showers in OWL - Airwatch

$E > 10^{19}$ GeV



Mass up to 10 Tera-tons

Area up to 10^6 km^2

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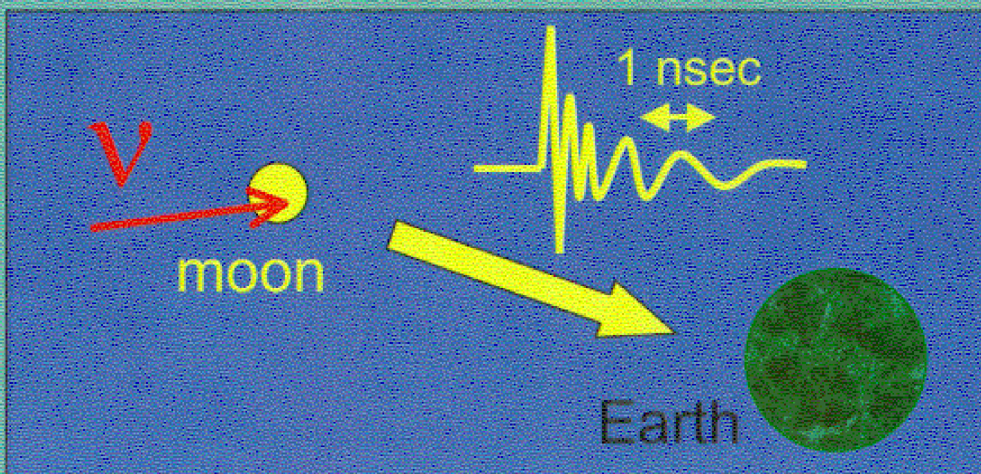
Superhigh Energies (2)

Lunar Radio Emissions from Interactions of ν and CR with $> 10^{19}$ eV

Gorham et al. (1999), 12 hr NASA Goldstone 70 m antenna + DSS 34 m antenna



$\rightarrow E^2 \cdot dN/dE < 10^{-5}$ GeV$\cdot$cm$^{-2}\cdot$s$^{-1}\cdot$sr^{-1}

at 10^{20} eV

Also proposed:
radar detection of ionization trail of EAS (Gorham)

Experiments at $> 10^{18}$ eV:

only a few events (blazars, TD, CR$\gamma_{2.7}$,...)

basically aimed for CR

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Superhigh Energies (2)

Lunar Radio Emissions from Interactions of ν and CR with > 10^{19} eV

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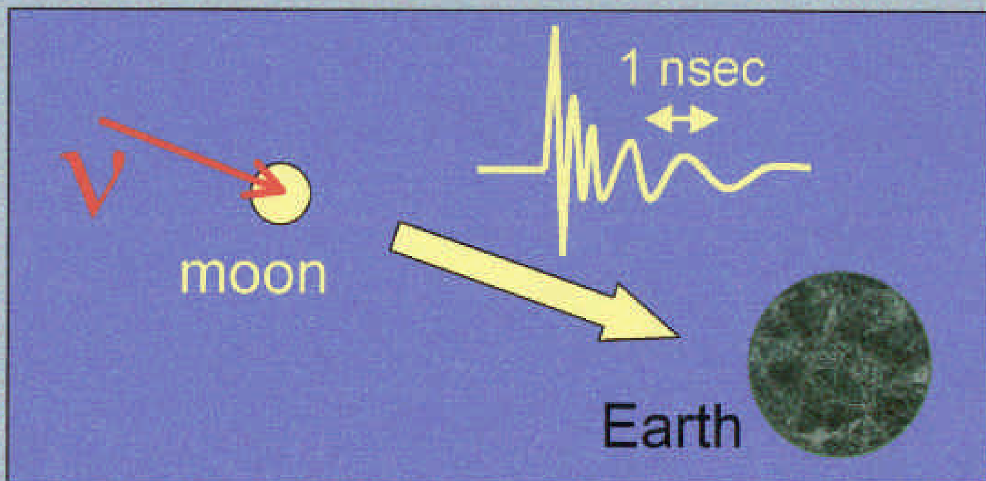

→ $E^2 \cdot dN/dE < 10^{-5}$ GeV·cm^{-2}·s^{-1}·sr^{-1}

at 10^{20} eV

Also proposed:
radar detection of ionization trail of EAS (Gorham)

Experiments at > 10^{18} eV:

either only a few events (blazars, TD, CR$\gamma_{2.7}$,...) or principally only upper limits (↔ CR)

all basically aimed for CR

C.Spiering, ν2000

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Conclusions

Conclusions

- BAIKAL and AMANDA see neutrinos with 10^3-10^4 m^2.
- The field has left the long period of infancy. Technologically and methodically still in learning phase.
- Mediterannean detector(s) - ANTARES, NESTOR - will follow soon.
- Need kilometer scale to prove „realistic models". One on each hemisphere: IceCube and Mediterranean.
- Need kilometer scale to open new window (increase in sensitivity by factor 100-1000 compared to existing devices)
- optical detectors may see only low energy part of interesting phenomena $\rightarrow$ develop (and fund!) radio and acoustic arrays ($\geq$ 10km^2 scale).
- complement HE frontier with a Mton detector with threshold of few GeV or lower.

C.Spiering, v2000