

Detection of neutral particles

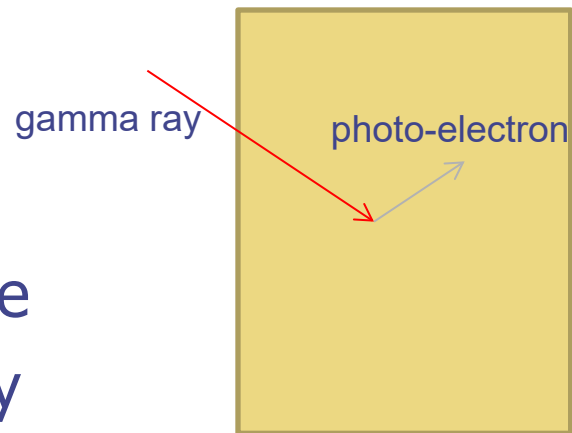
detection of neutrons

detection of neutrinos

(detection of high energy photons → calorimeters)

Detection of neutral particles

Detection of neutral particles = let them interact with the detector medium, detect resulting charged particles.



Similar to what we had in gamma-ray detectors

Detection of neutrons

In principle similar to the gamma-ray detection:
again let the neutron interact with the
detector medium, and detect charged
reaction products

Detection of low energy n: n+nucleus → charged fragments

Three conversion reactions commonly used in detectors:



Because the **energy released** in these reactions is **large** compared to the **energy of the detected neutron**, and the reaction products (which we later detect) carry away this released energy, the information on the neutron energy is lost.

Detection of low energy n: n+nucleus -> charged fragments

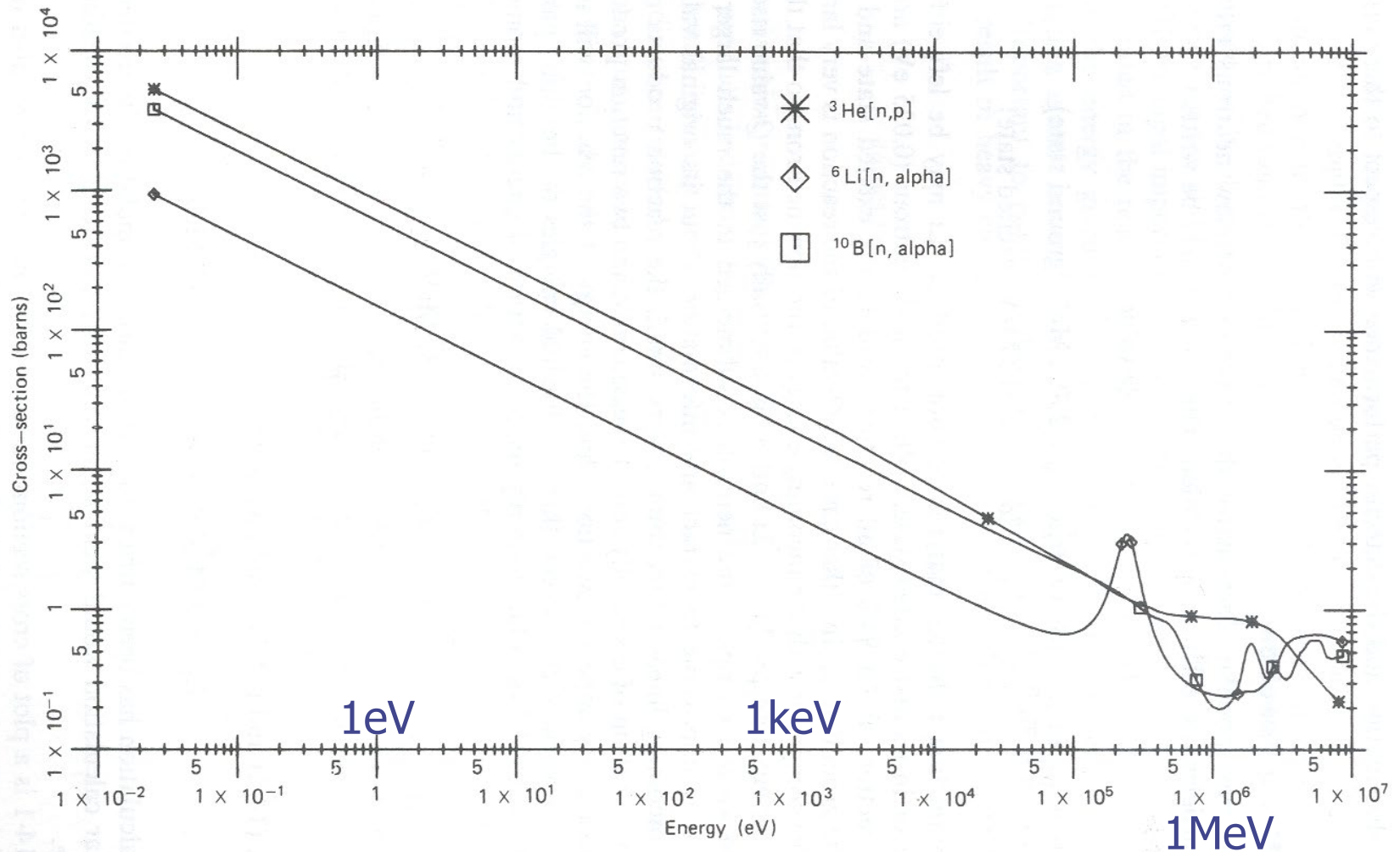
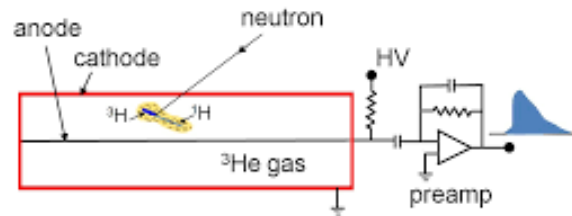


Figure 14-1 Cross section versus neutron energy for some reactions of interest in neutron detection.

Slow neutron detection counters

The boron reaction is employed in BF_3 proportional tubes where boron trifluoride is used as a proportional gas. The BF_3 gas is usually enriched in ^{10}B , and it has to be used at lower absolute pressures between 0.5 and 1.0 atm in order to get a good performance as a proportional gas.



In a similar way, ^3He is used as a conversion target and proportional gas in the ^3He proportional counter. Due to the lower energy released in the $^3\text{He}(n,p)$ reaction, the discrimination of gamma rays is more difficult than with BF_3 counters, since secondary electrons only deposit a small amount of energy in the gas.

Neutron detectors with Li

^6Li is usually used in scintillators, e.g. lithium iodide, which is chemically similar to sodium iodide. Due to the density of enriched $^6\text{LiI}(\text{Eu})$ crystals, a 10 mm thick detector is almost 100% efficient for neutrons ranging from thermal energies up to about 0.5 eV.

Lithium is also incorporated in scintillating glass matrices. Lithium glass scintillators are used in time-of-flight measurements due to their relatively fast time response of less than 100 ns. This type of detector, however, is more commonly used in the detection of neutrons with intermediate energies.

Neutrons with T around 1MeV

Cross section much lower than for thermal neutrons – employ a moderator where neutrons lose energy after elastic scattering – most efficient if it has a large fraction of hydrogen (e.g. organic compounds like polyethylene and paraffin)

Neutron detection: combination of several methods

^3He

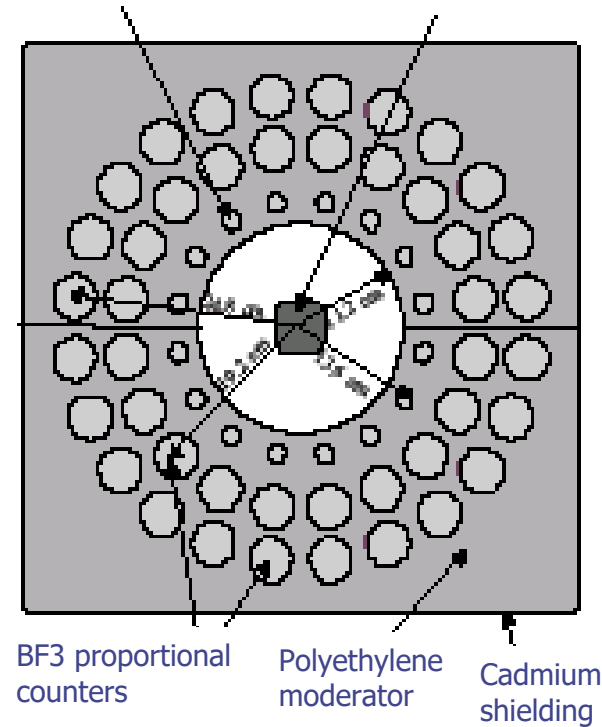
BF_3

moderator

shield

^3He proportional counter

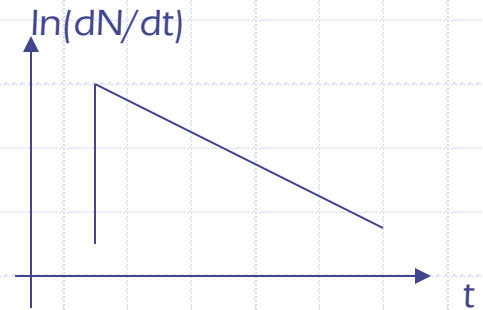
Si detector



Discrimination against gamma rays

Some scintilators have two decay constants

$$dN/dt = A \exp(-t/\tau_1) + B \exp(-t/\tau_2)$$



→ In such scintillation materials the ratio of the two components depends on the particle type since the light yield of the two components depends on dE/dx , which, in turn, depends on the particle type.

→

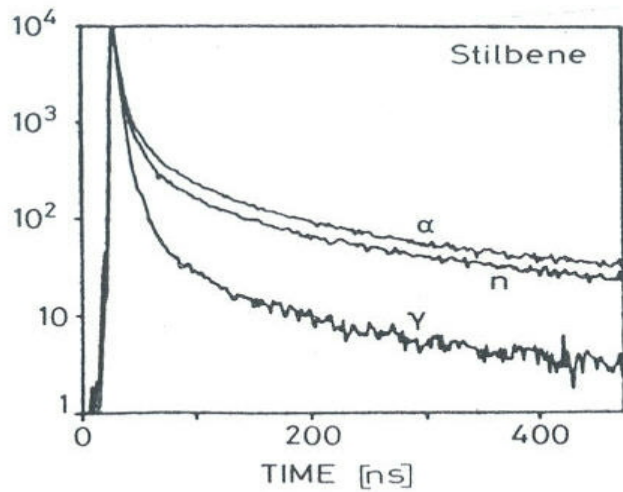


Fig. 7.11. Pulse shape of stilbene light for alpha particles, neutrons, and gamma rays (from *Lynch* [7.71]; picture © 1975 IEEE)

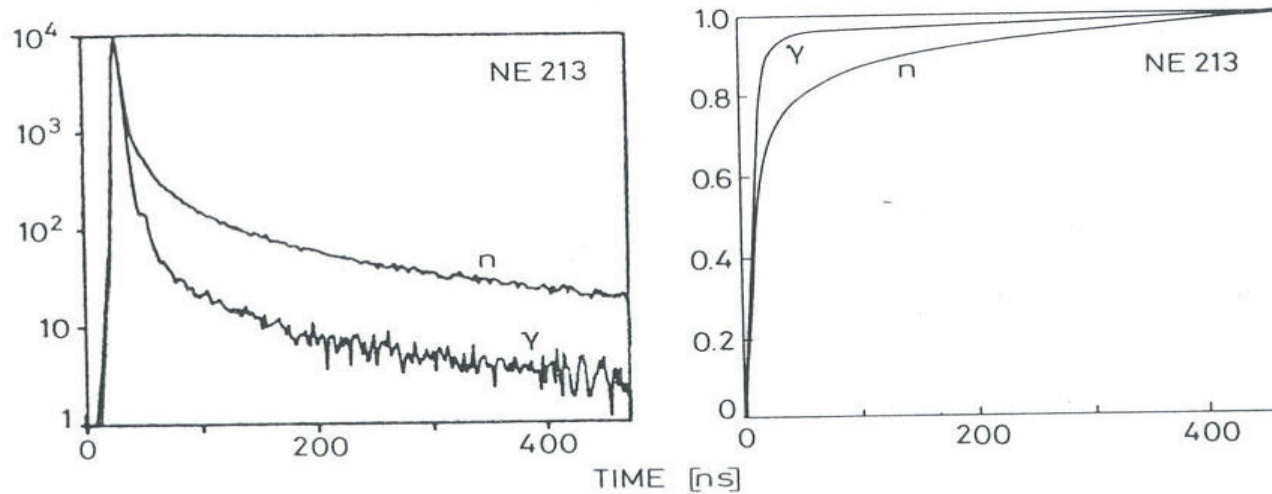


Fig. 7.12. Pulse shape differences of NE213 liquid scintillator light for neutrons and gamma rays. The time integral of the light pulses is also shown. A discrimination between these radiations may be obtained by measuring the time it takes for the integrated pulse to reach a certain fixed level (from *Lynch* [7.17]; picture © 1975 IEEE)

Medium energy neutrons (=fast n)

For neutrons of even higher energies ($20\text{MeV} < T < 1\text{GeV}$) the use of a moderator is unpractical, furthermore, moderator based detectors are slow and cannot be used for time measurements.

The most common method to detect fast neutrons is based on elastic scattering of neutrons on light nuclei, resulting in a recoil nucleus. This is also the principle of proton recoil scintillators. Fast neutrons incident on a hydrogen-containing scintillator will scatter elastically and give rise to recoil protons ranging in energy up to the full neutron energy. The energy of the recoil protons is then deposited in the scintillator and converted to fluorescence.

A large variety of hydrogen-containing scintillators is available: organic crystals (anthracene, stilbene), liquid scintillators (organic scintillators in an organic solvent), and plastic scintillators (organic scintillators in a polymerized hydrocarbon)

High energy neutrons

For neutrons with several GeV energy: hadron calorimeters → lecture 'Energy measurements'

Neutrino detection

Use inverse beta decay

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

$$\bar{\nu}_e + p \rightarrow n + e^+$$

$$\nu_\mu + n \rightarrow p + \mu^-$$

$$\bar{\nu}_\mu + p \rightarrow n + \mu^+$$

$$\nu_\tau + n \rightarrow p + \tau^-$$

$$\bar{\nu}_\tau + p \rightarrow n + \tau^+$$

However: cross section is very small!

$$6.4 \cdot 10^{-44} \text{ cm}^2 \text{ at } 1\text{MeV}$$

Probability for interaction in 100m of water = $4 \cdot 10^{-16}$

Neutrino detection - history



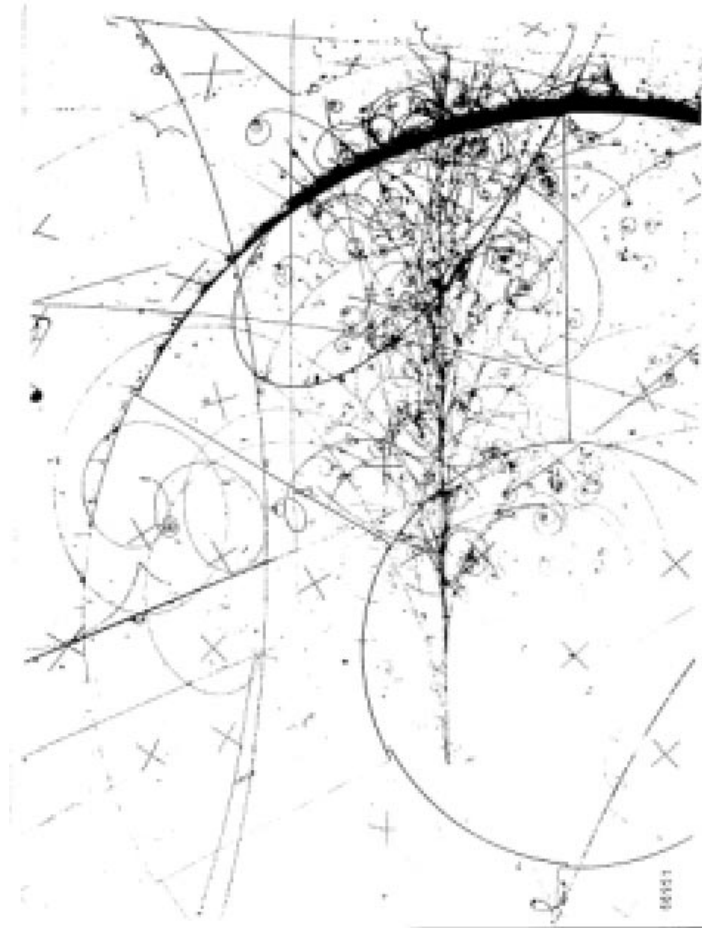
Reines-Cowan experiment



Davies experiment

Electron neutrino detected in a bubble chamber

Electron neutrino produces an electron, which then starts a shower. Tracks of the shower are curved in the magnetic field.



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Which type of neutrino?

Identify the reaction product, e, μ, τ , and its charge.

Water detectors (e.g. Superkamiokande)

muon: a sharp Cherenkov ring

electron: Cherenkov ring is blurred (e.m. shower development)

tau: decays almost immediately – after a few hundred microns to one or three charged particles

High energy neutrinos

Interaction cross section:

Neutrinos:

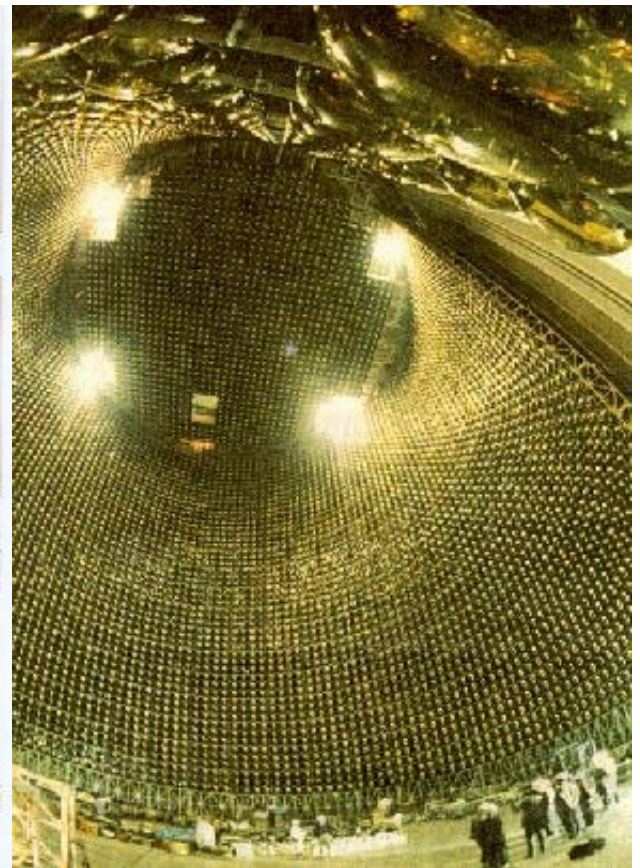
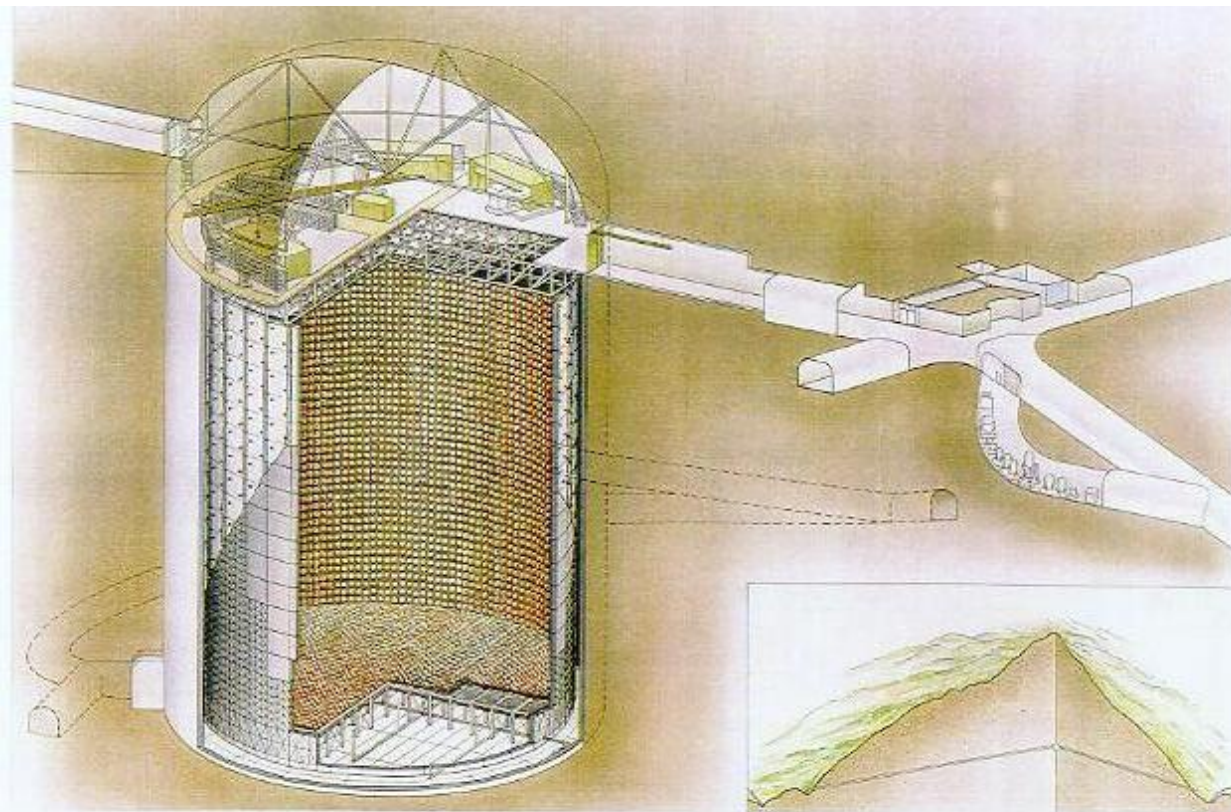
$0.67 \cdot 10^{-38} E/1\text{GeV cm}^2$ per nucleon

Antineutrinos:

$0.34 \cdot 10^{-38} E/1\text{GeV cm}^2$ per nucleon

At 100 GeV, still 11 orders below
the proton-proton cross section

Superkamiokande: an example of a neutrino detector

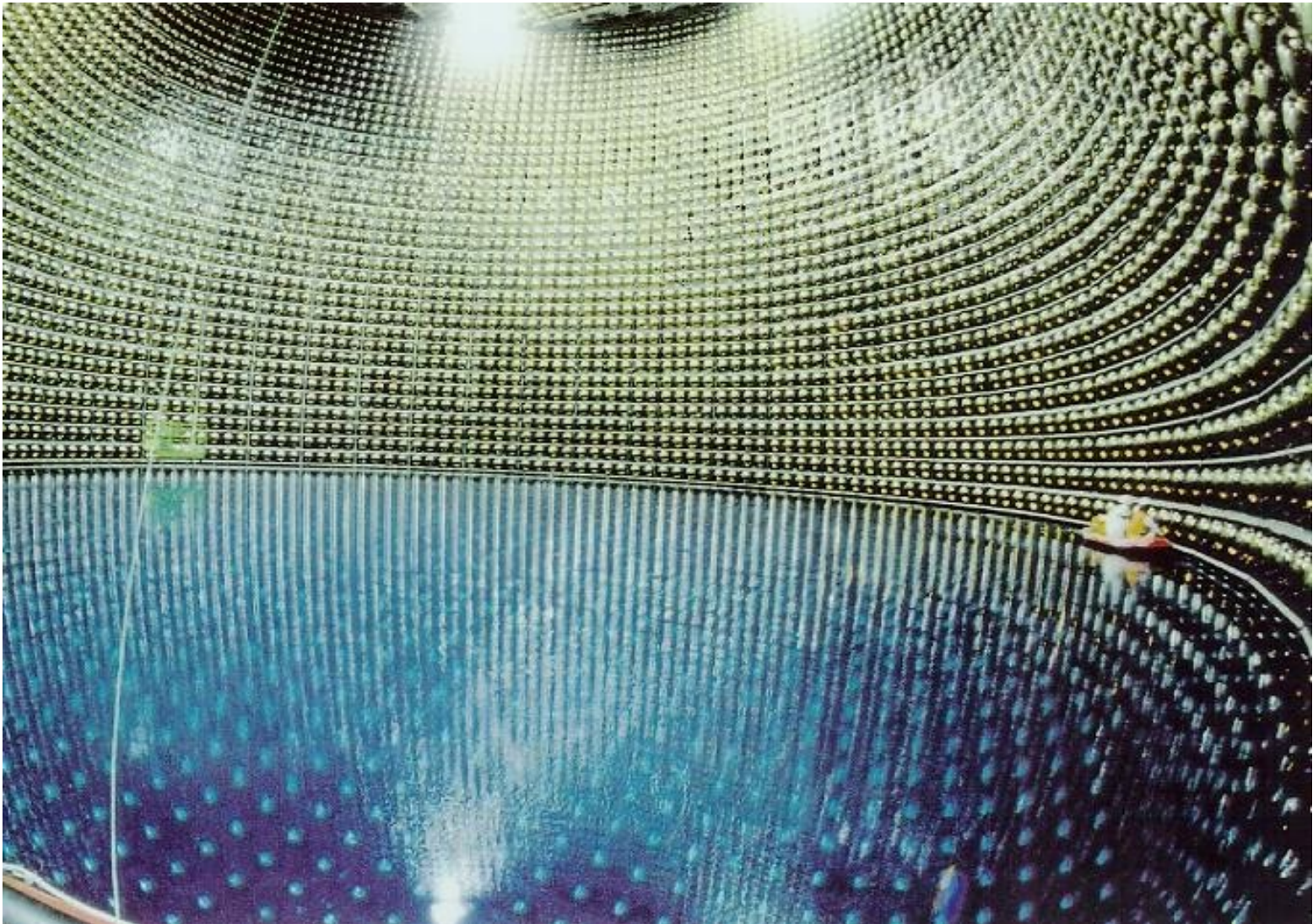


SUPERKAMIOKANDE INSTITUTE FOR COSMIC RAY RESEARCH UNIVERSITY OF TOKYO

NIKKEN SEKKI

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Superkamiokande: an example of a neutrino detector



Superkamiokande: detection of Cherenkov photons

Light sensors: HUGE
photomultiplier tubes

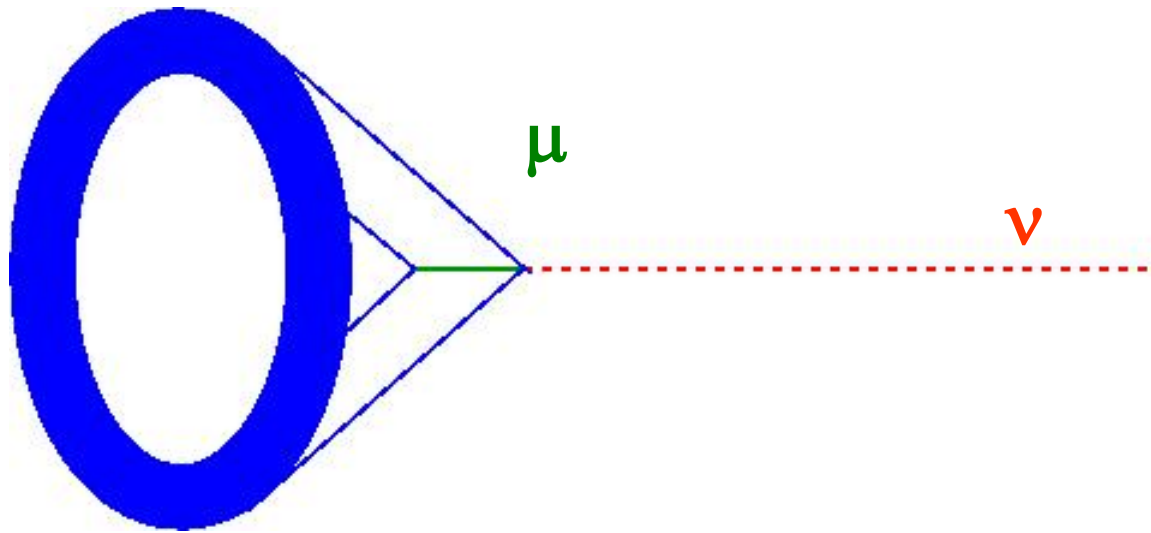


M. Koshihara

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Superkamiokande: detection of electrons and muons

How to detect muons or electrons? Again through Cherenkov radiation, this time in the water container. Neutrino turns into an electron or muon.



Muons and electrons emit Cherenkov photons
→ ring at the container walls

- Muon ring: sharp edges
- Electron ring: blurred image (bremstrahlung)

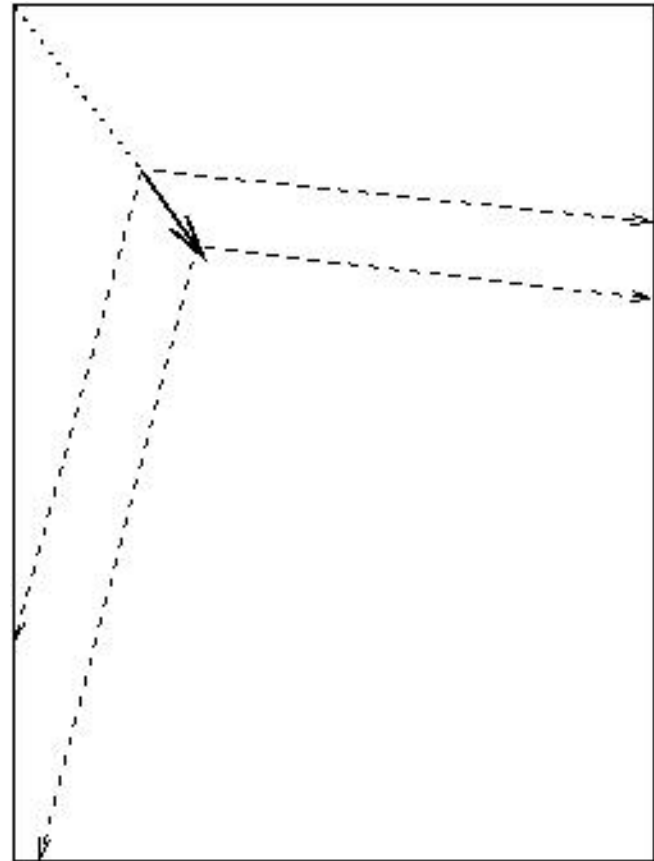
Muon vs electron

Cherenkov photons from a muon track:

Example: 1GeV muon neutrino

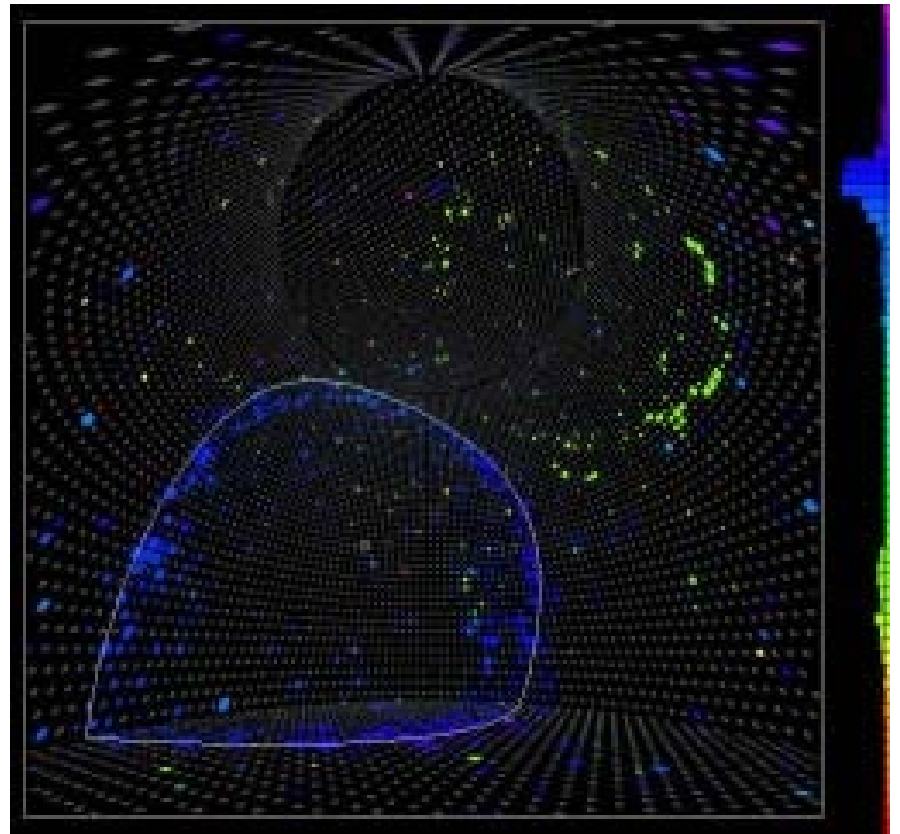
Track length of the resulting muon: $L = E / (dE/dx) = 1\text{GeV} / (2\text{MeV/cm}) = 5\text{m}$

→ a well defined “ring” on the walls



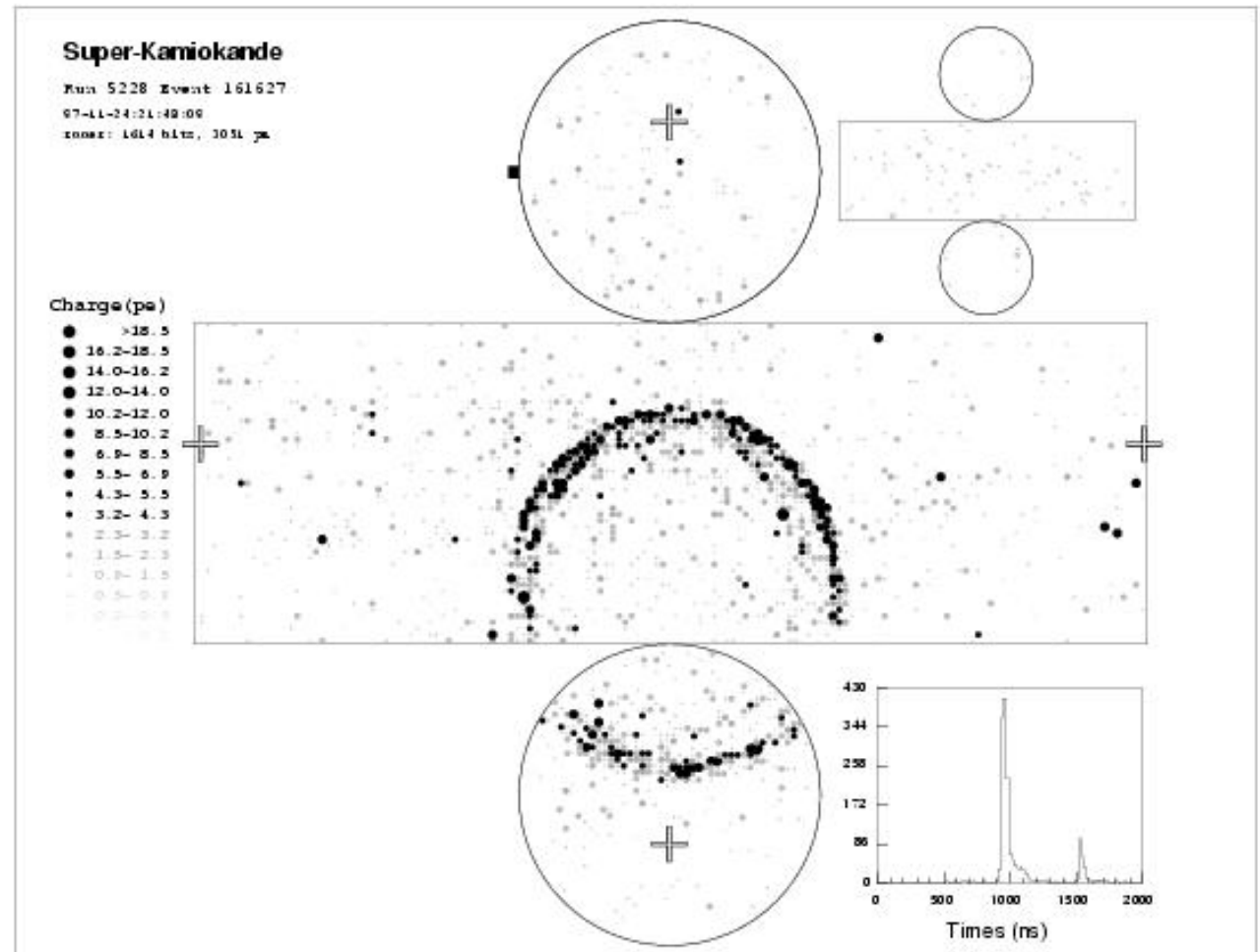
Superkamiokande: muon event

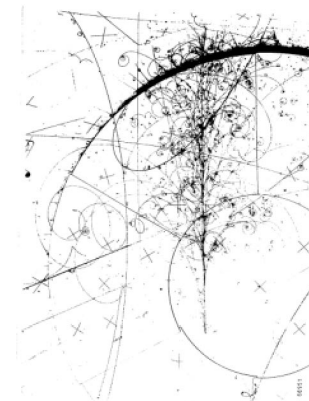
Muon 'ring' as seen by the
photon detectors



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Muon event: photon detector cylinder walls





Cherenkov photons from an electron track

Electron starts a shower!

Cherenkov photons from an
electron generated shower

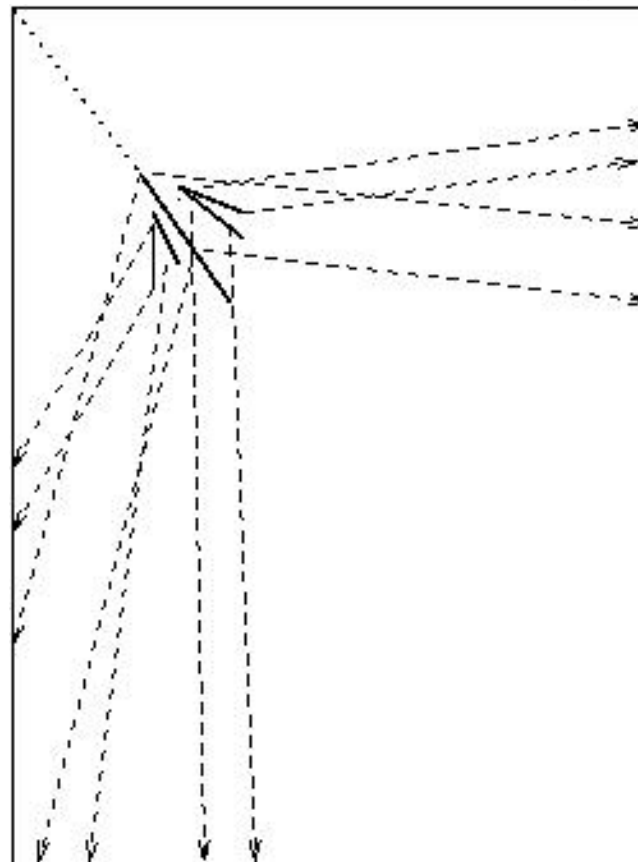
Example: 1GeV el. neutrino

Shower length:

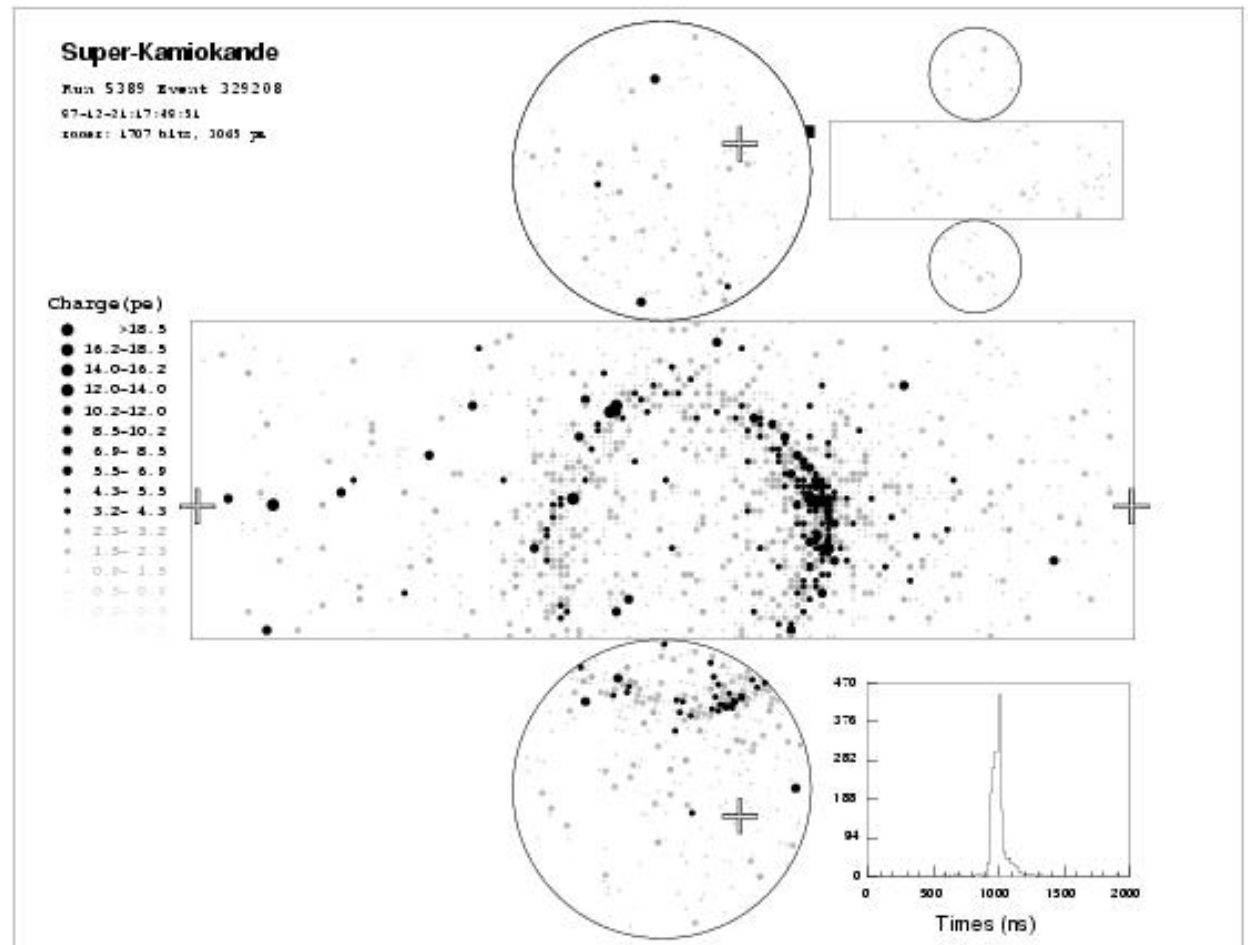
$$L = X_0 * \log_2(E/E_{\text{crit}}) =$$
$$36\text{cm} * \log_2(1\text{GeV}/10\text{MeV})$$
$$= 2.5\text{m}$$

Shower particles are not parallel
to each other

-> a blurred, less well defined
"ring" on the walls



Electron event: blurred ring



Detection of very high energy neutrinos (from galactic sources)

The expected fluxes are very low:

Need really huge volumes of detector medium!

What is huge? From $(100\text{m})^3$ to $(1\text{km})^3$

Also needed: directional information.

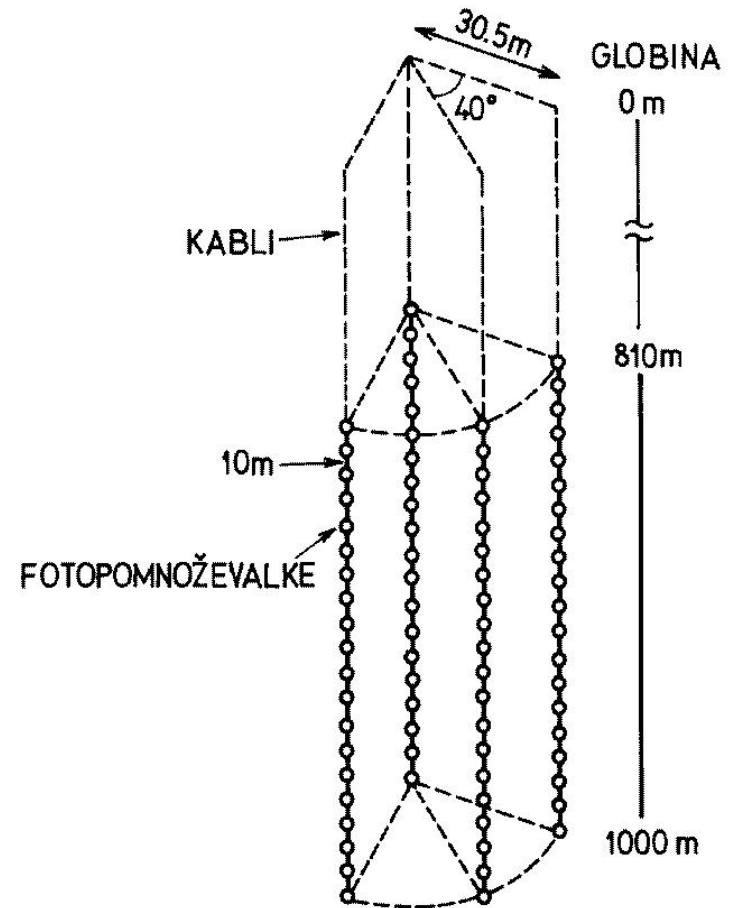
Again use: $\nu_{\mu} + n \rightarrow p + \mu^{-}$; μ direction coincides with the direction of the high energy neutrino.

AMANDA: use the Antarctic ice instead of water

Normal ice is not transparent due to Rayleigh scattering on inhomogeneities (air bubbles)

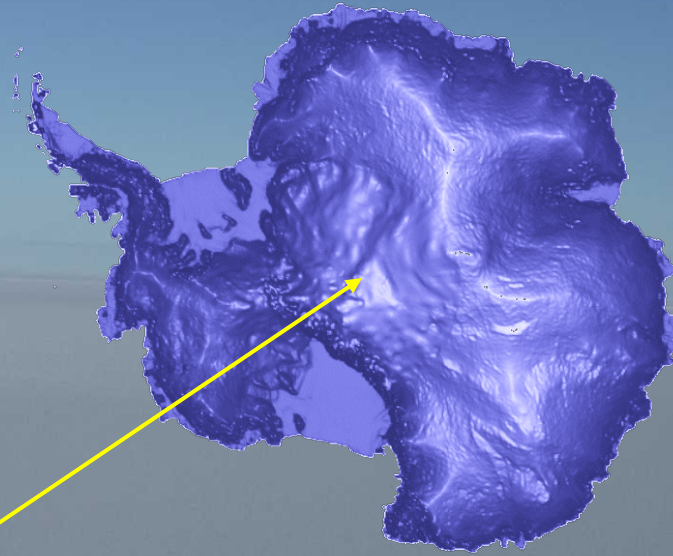
At high pressures (large depth) there is a phase transition, bubbles get partly filled with water -> transparent!

Originally assumed: below 800m OK; turned out to be much deeper.



AMANDA

- 1993 First strings AMANDA A
- 1998 AMANDA B10 ~ 300 Optical Modules
- 2000 AMANDA II ~ 700 Optical Modules
- 2010 ICECUBE 4800 Optical Modules



AMANDA

South Pole

Dome

road to work

Summer camp

1500 m

2000 m

[not to scale]

Amundsen-Scott South Pole station

Reconstruction of direction and energy of incident high energy muon neutrino

For each event:

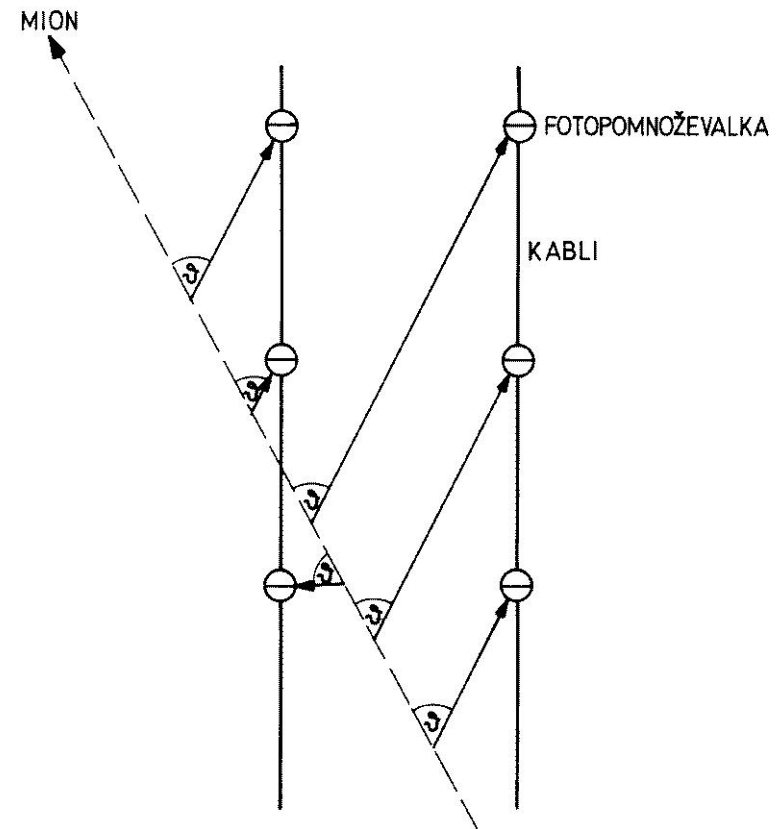
Measure time of arrival on each of the tubes

Cherenkov angle is known:
 $\cos\theta = 1/n$

Reconstruct muon track

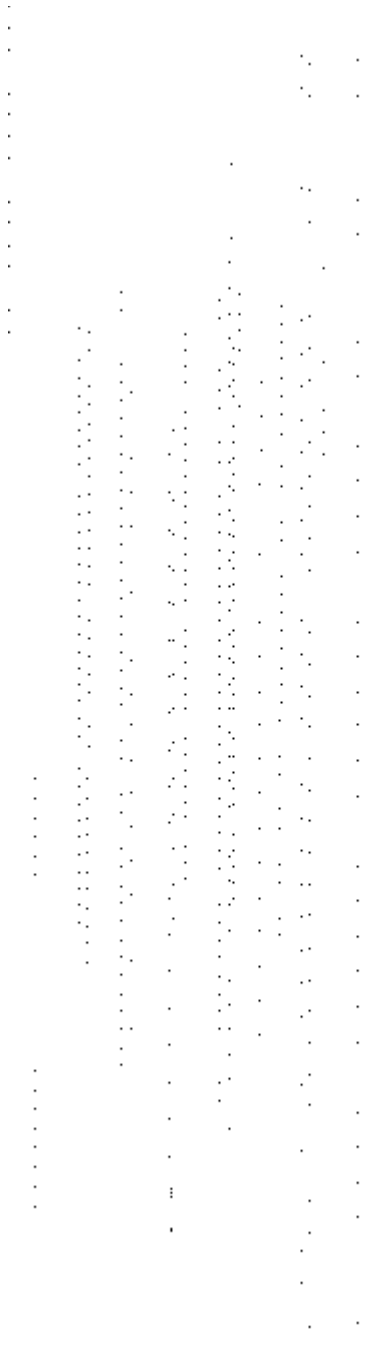
Track direction \rightarrow neutrino direction

Track length \rightarrow neutrino energy



AMANDA

Example of a detected event, a muon entering the PMT array from below

A vertical array of PMTs is shown as a series of vertical lines of dots. A blue arrow points upwards from the bottom right towards the array, indicating the direction of a muon entering from below.

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