Detekcija nevtrinov

Ugriznimo v znanost, 9.11.2015

Nevtrino: nevtralen delec, kako ga zaznati?

Preko reakcije: $\nu_e + n \rightarrow p + e^-$

Pozor: verjetnost za reakcijo je zelo majhna!

V 100m vode je verjetnost za reakcijo = 4 10^{-16}

(miljoninka milijardinke)

Potrebujemo: ali

- velikanski detektor ali pa
- močen izvor nevtrinov

Tri vrste nevtrinov: ν_e , ν_μ , ν_τ

Kako vem, kateri je od njih je priletel v detektor?

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

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

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

Nevtrino ali antinevtrino?

$\nu_e + n \rightarrow p + \mathbf{e^-}$

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

Detekcija nevtrinov – zgodovina 1

Eksperiment Reinesa in Cowana (1956);

→Močen izvor (anti)nevtrinov: jedrski reaktor
→Detektor: tank z vodo, okoli detektorji žarkov gama

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

$$e^+ + e^- \rightarrow \gamma\,\gamma$$

$$n + Cd \rightarrow Cd^* \rightarrow Cd + \gamma$$

F. Reines: Nobelova nagrada 1995

Detekcija nevtrinov – zgodovina 2

Davisov eksperiment

→Nevtrini iz Sonca

→Detektor: tank z ogljikovim tetrakloridom $C\,Cl_4$

→Globoko pod zemljo (rudnik Homestake)

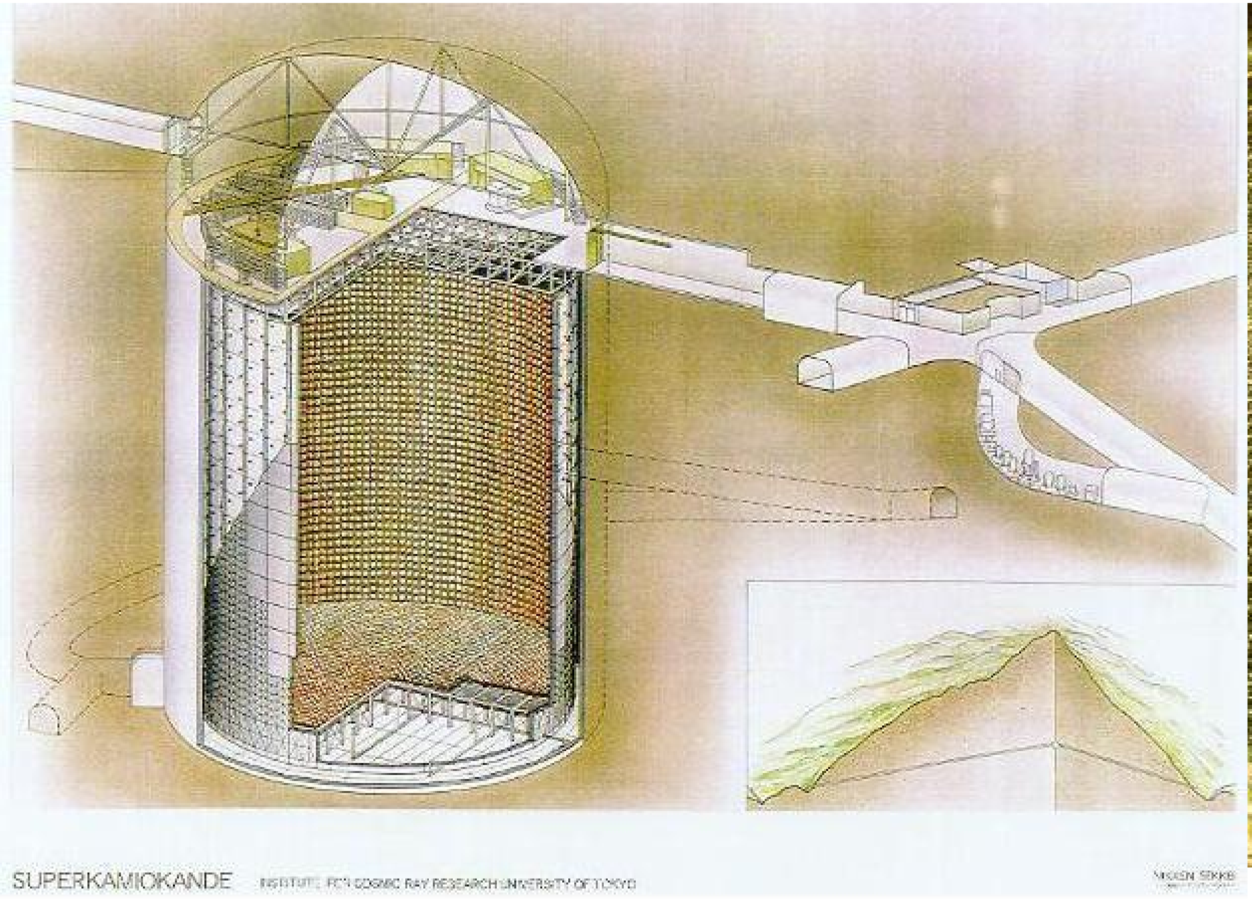
Reakcija: $\nu_e + n \rightarrow p + e^-$

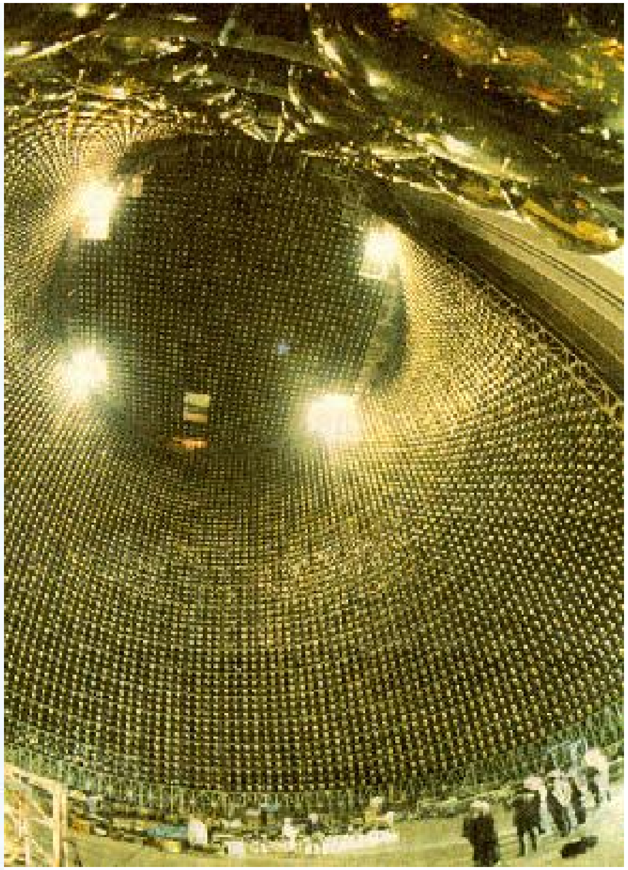
$\nu_e + {}^{37}Cl \rightarrow {}^{37}Ar^* + e^-$

${}^{37}Ar^* \rightarrow {}^{37}Ar + \gamma$

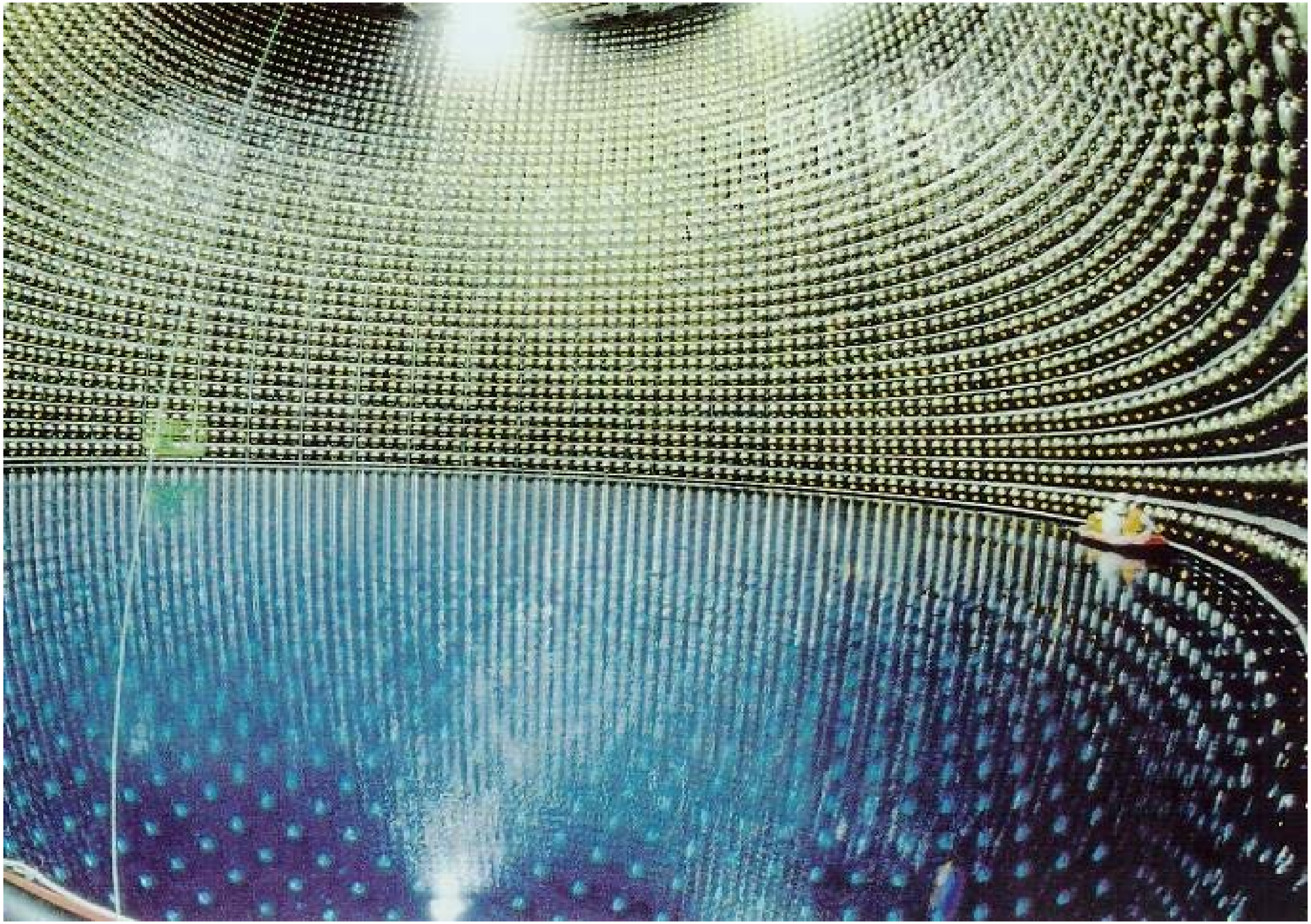
→R. Davis: Nobelova nagrada 2002

Superkamiokande: primer nevtrinskega detektorja





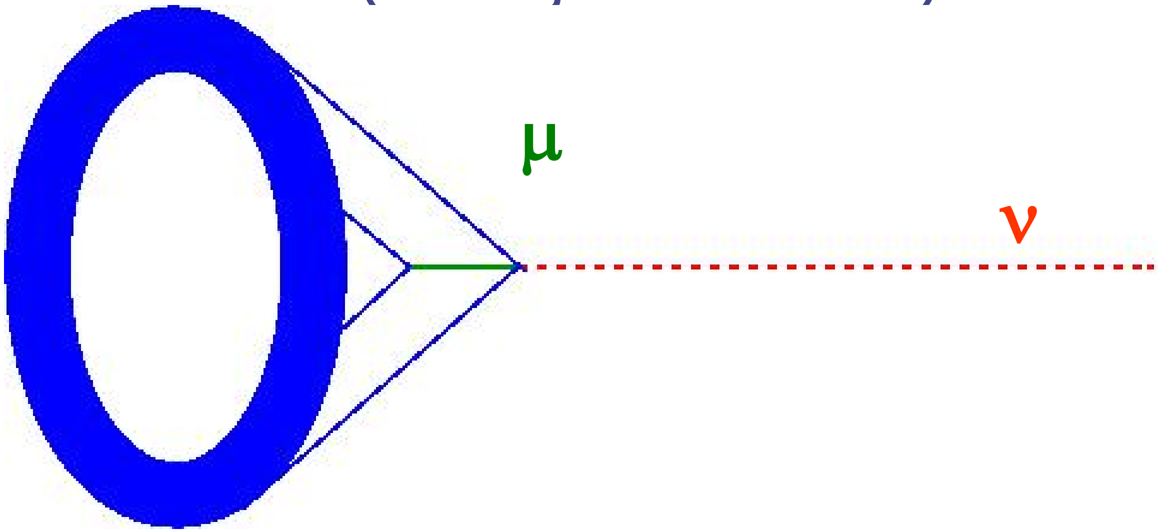
Superkamiokande: primer nevtrinskega detektorja



Superkamiokande: detekcija netrinov preko detekcije elektronov oziroma mionov

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

Mion z veliko hitrostjo potuje po vodi, seva svetlobo po določenim kotom (sevanje Čerenkova)



Svetlobo zaznamo z zelo občutljivimi senzorji na stenah posode

Superkamiokande: detekcija Čerenkove svetlobe

Senzorji svetlobe: VELIKANSKE fotopomnoževalke

Masatoshi Koshiba, U. Tokijo
Nobelova nagrada 2002

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:

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

Antineutrinos:

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

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

Superkamiokande: an example of a neutrino detector

Kamiokande Detector ("Kamioka Nucleon Decay Experiment"):
1000 8" PMTs in 4500-tonne pure water target

Limits on proton decay,
First detection of neutrinos from supernova,
11 events from SN in Large Magellanic Cloud, Feb 23, 1987

Super-Kamiokande Detector
11000 20" + 1900 8" PMTs in 50000-tonne pure water target

- Operation since 1996, measurements of neutrino oscillations via up down asymmetry in atmospheric ν rate
- Solar ν flux (all types) 45% of that expected
- Accident November 2001: loss of 5000 20" PMTs, now replaced

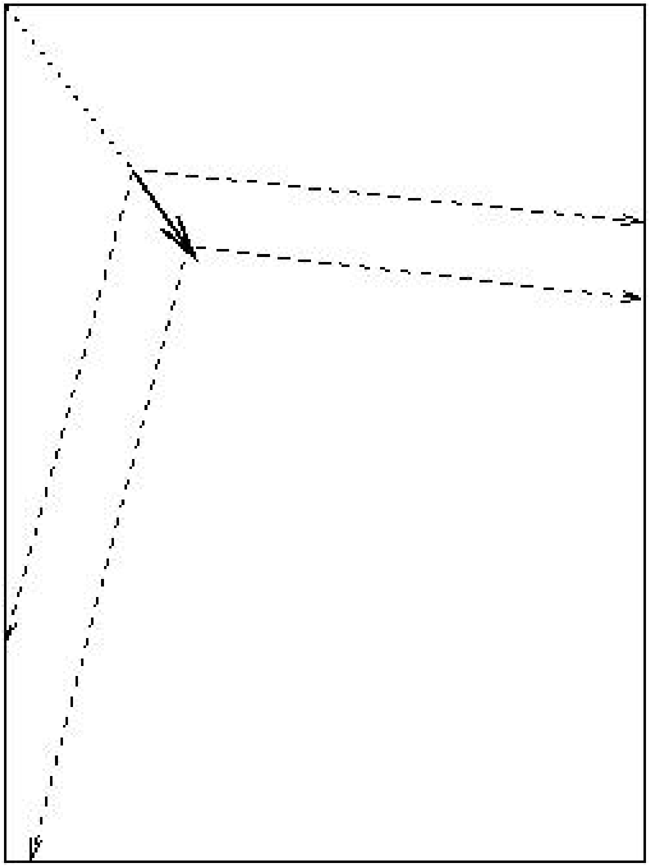
Muon vs electron

Cherenkov photons from a muon track:

Example: 1GeV muon neutrino

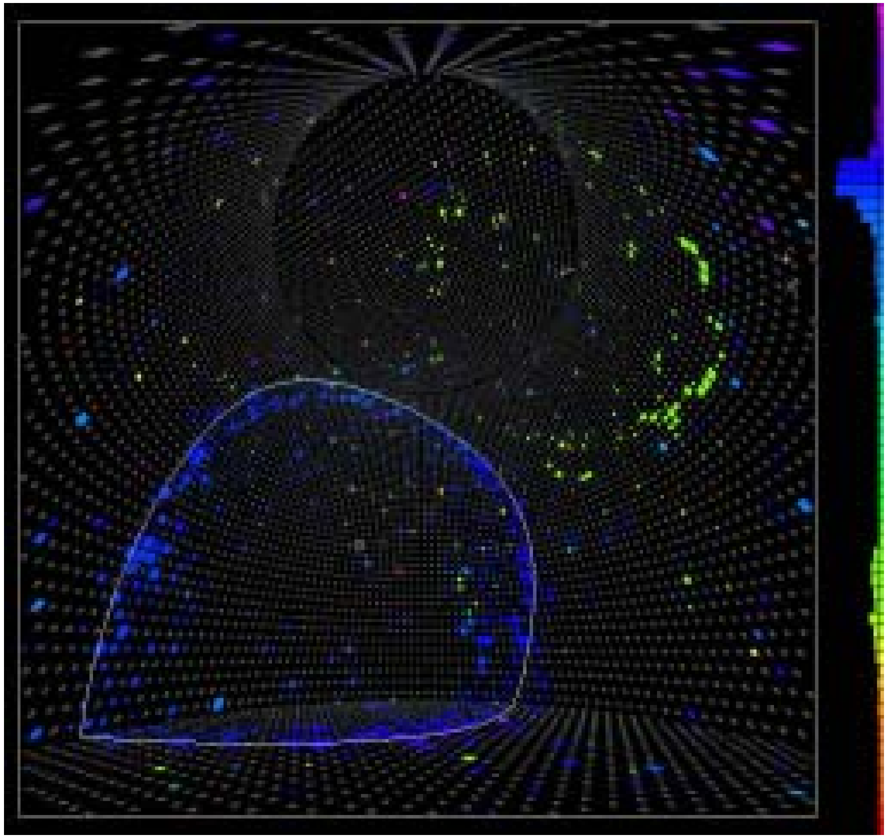
Track length of the resulting muon: $L=E/(dE/dx)= =1GeV/(2MeV/cm)=5m$

→ a well defined "ring" on the walls

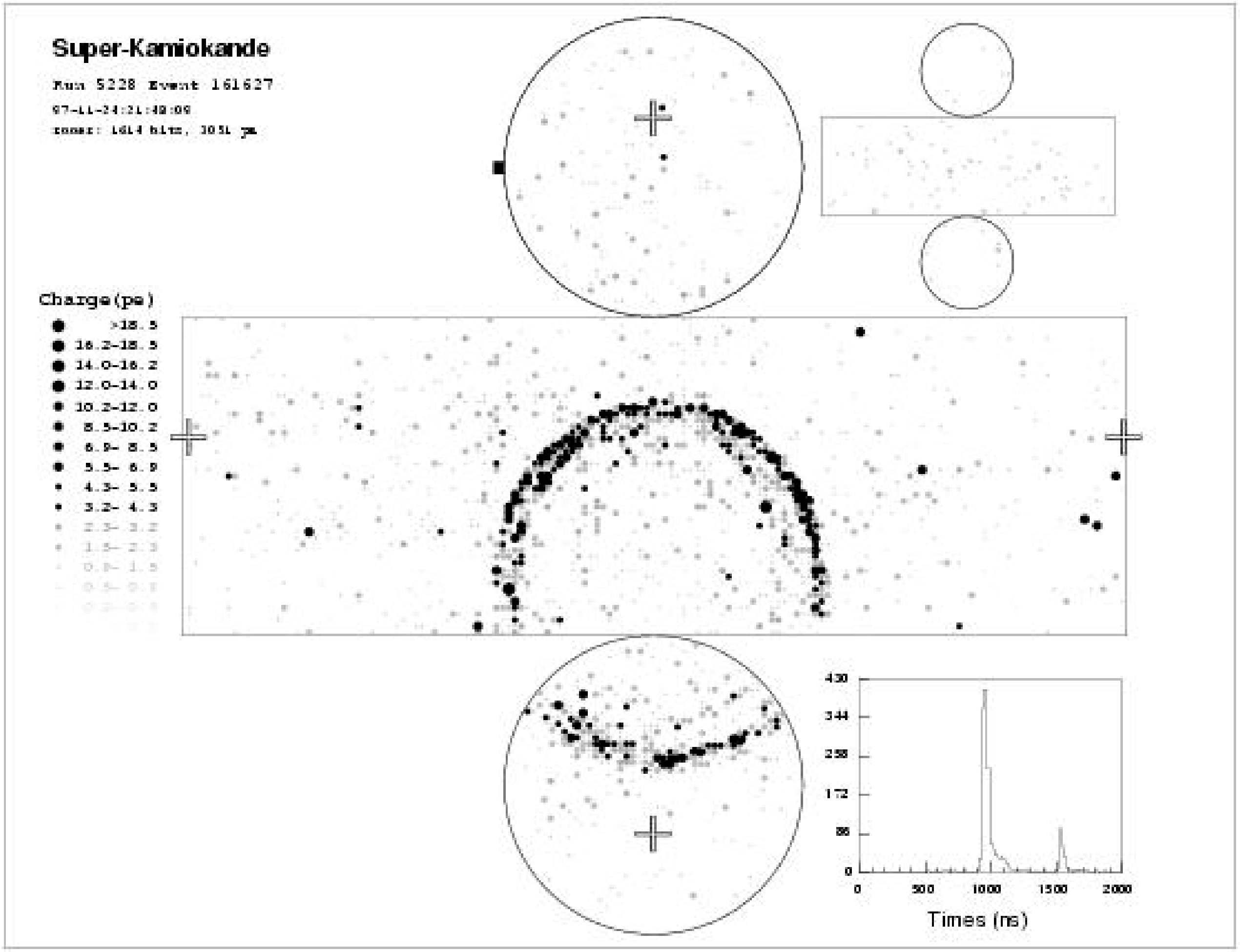


Superkamiokande: muon event

Muon ‘ring’ as seen by the photon detectors



Muon event: photon detector cillinder walls



Cherenkov photons from an electron track

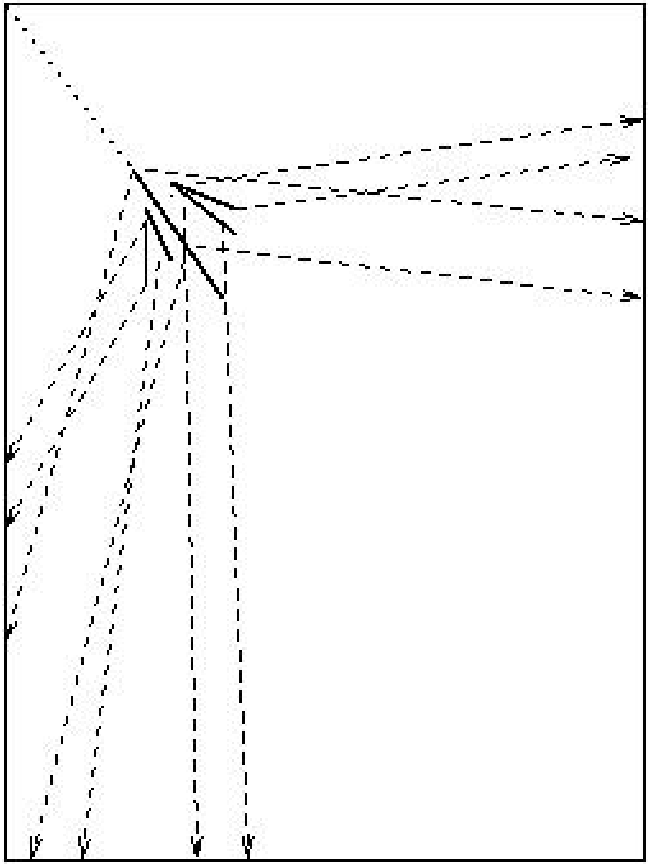
Electron starts a shower!

Cherenkov photons from an electron generated shower

Example: 1GeV el. neutrino

Shower length:

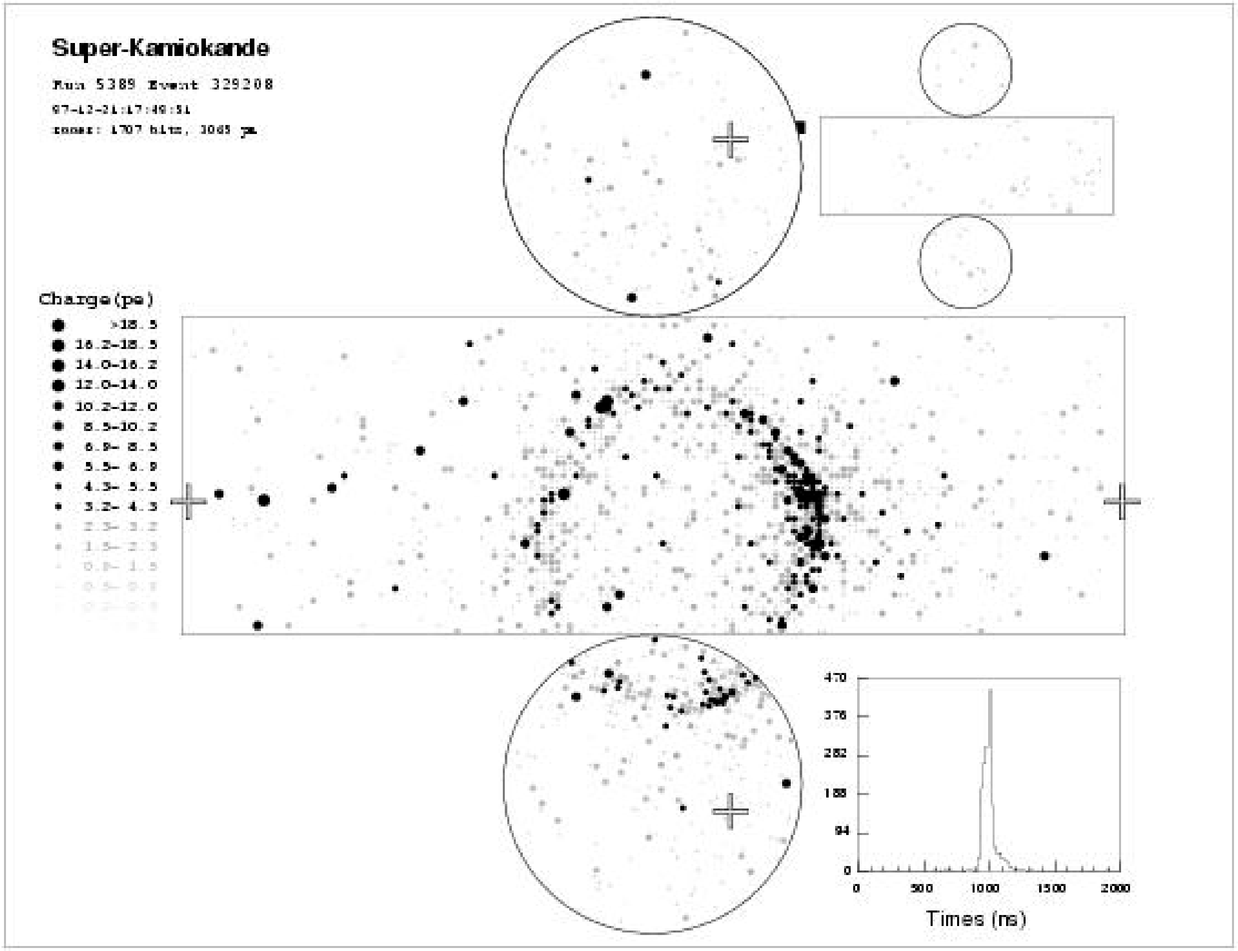
$L = X_0 * \log_2(E/E_{crit}) = 36\text{cm} * \log_2(1\text{GeV}/10\text{MeV}) = 2.5\text{m}$



Shower particles are not parallel to each other

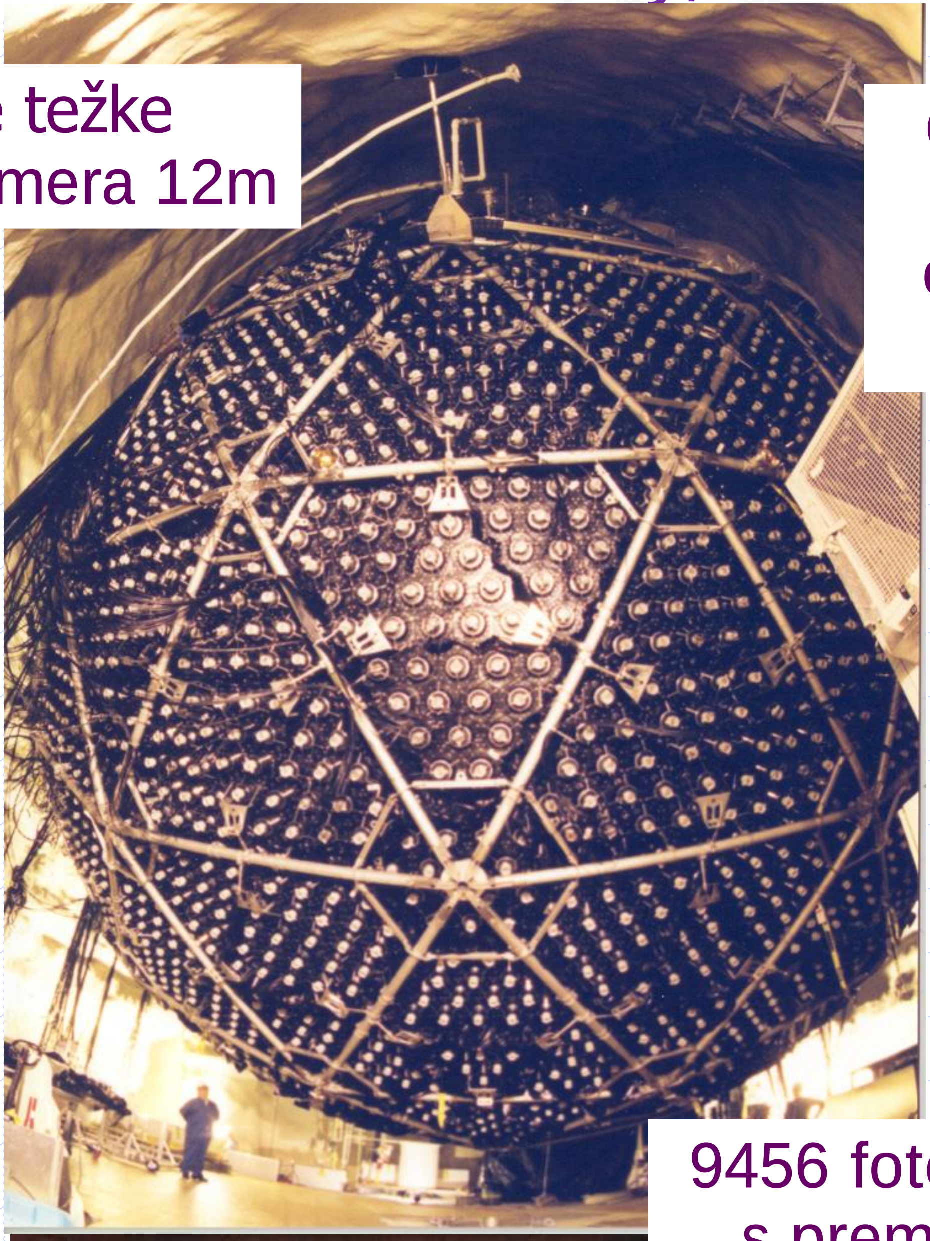
-> a blurred, less well defined “ring” on the walls

Electron event: blurred ring



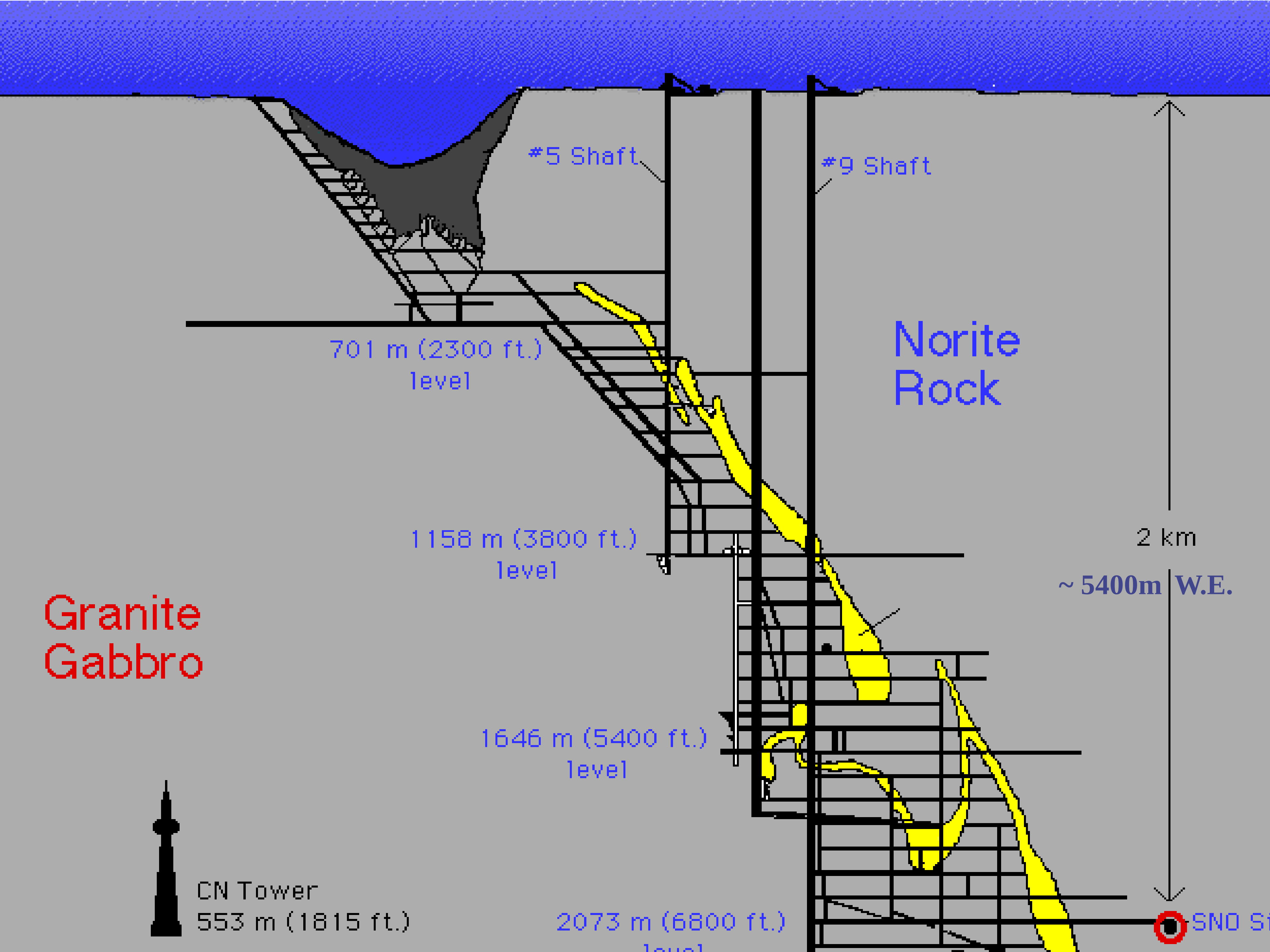
Sudbury Neutrino Observatory, Ontario, Kanada

1000 ton čiste težke vode v krogli premera 12m



Čista navadna voda kot ščit okoli posode s težko vodo

9456 fotopomnoževalk s premerom 20 cm


#5 Shaft
#9 Shaft
Norite
Rock
701 m (2300 ft.)
level
1158 m (3800 ft.)
level
2 km
~ 5400m W.E.
Granite
Gabbro
1646 m (5400 ft.)
level
CN Tower
553 m (1815 ft.)
2073 m (6800 ft.)

Sudbury Neutrino Observatory

Zaradi težke vode (D_2O, D – devterij = jedro s po enim protonom in netvronom) lahko detektor SNO zaznava vse tri vrste nevtrinov

ν Reactions in SNO

CC $\nu_e + d \Rightarrow p + p + e^-$ → Č light

- Good measurement of ν_e energy spectrum
- Weak directional sensitivity ∝ 1-1/3cos(θ)
- ν_e only.

NC $\nu_x + d \Rightarrow p + n + \nu_x$

- Equal cross section for all ν types
- Measure total ^8B ν flux from the sun.

n captured by another deuteron → γ scatters e → Č light

ES $\nu_x + e^- \Rightarrow \nu_x + e^-$ → Č light

Detection of very high energy neutrinos (from galactic sources)

The expected fluxes are very low:

Need really huge volumes of detector medium!

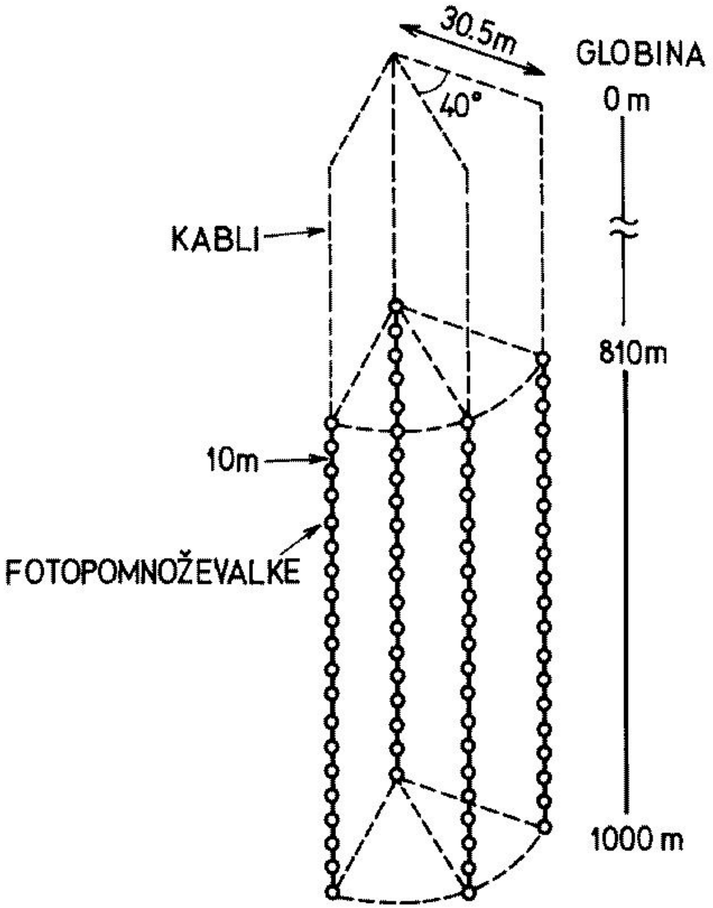
What is huge? From $(100m)^3$ to $(1km)^3$

Also needed: directional information.

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

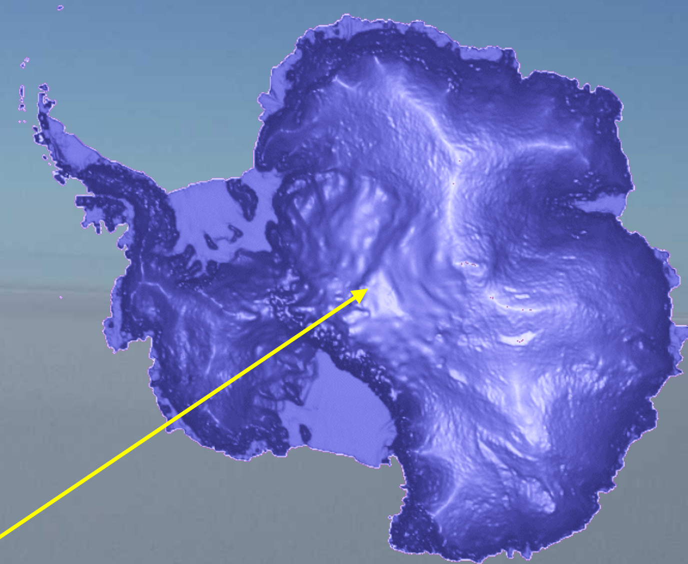
AMANDA: use the Antarctic ice instead of water

- Normal ice is not transparent due to Rayleigh scattering on inhomogenuities (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



Reconstruction of direction and energy of incident high energy muon netrino

For each event:

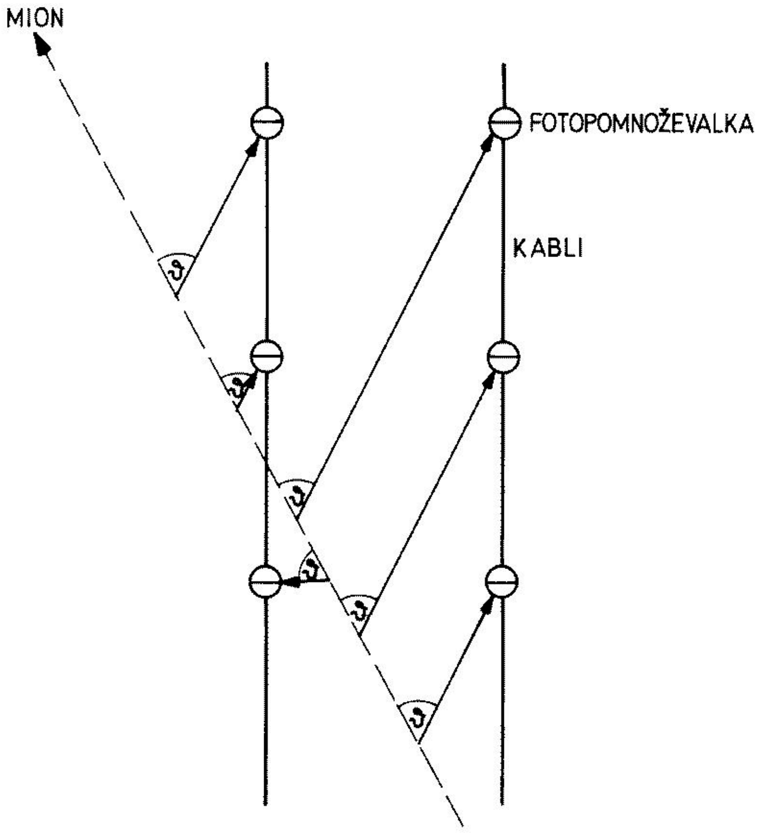
Measure time of arrival on each of the tubes

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

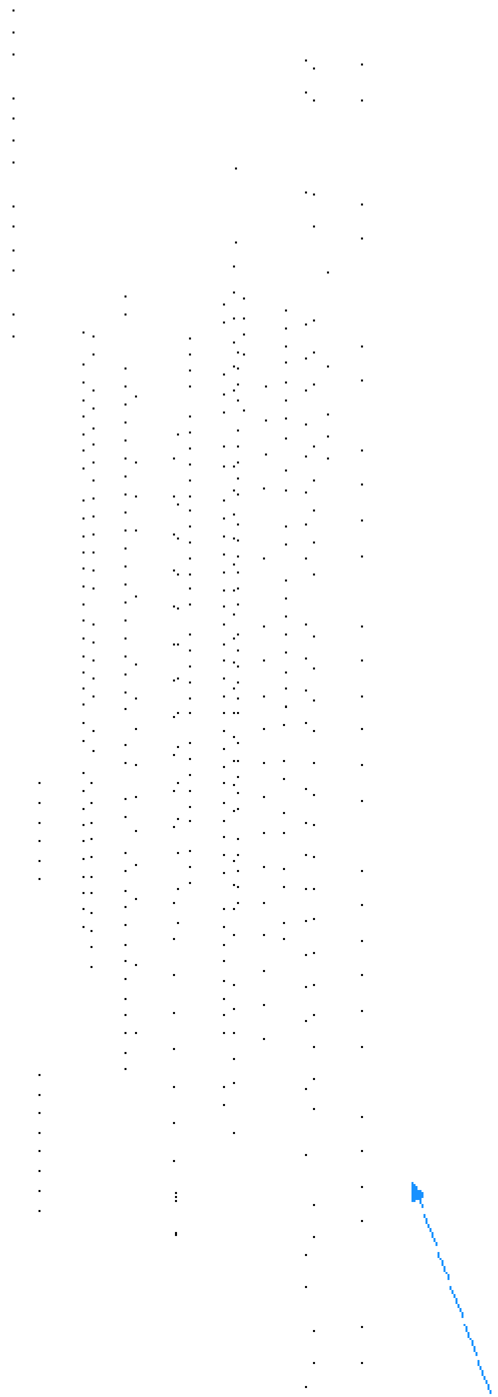
Reconstruct muon track

Track direction -> neutrino direction

Track length -> neutrino energy



AMANDA



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

Neutrino detection arrays in water

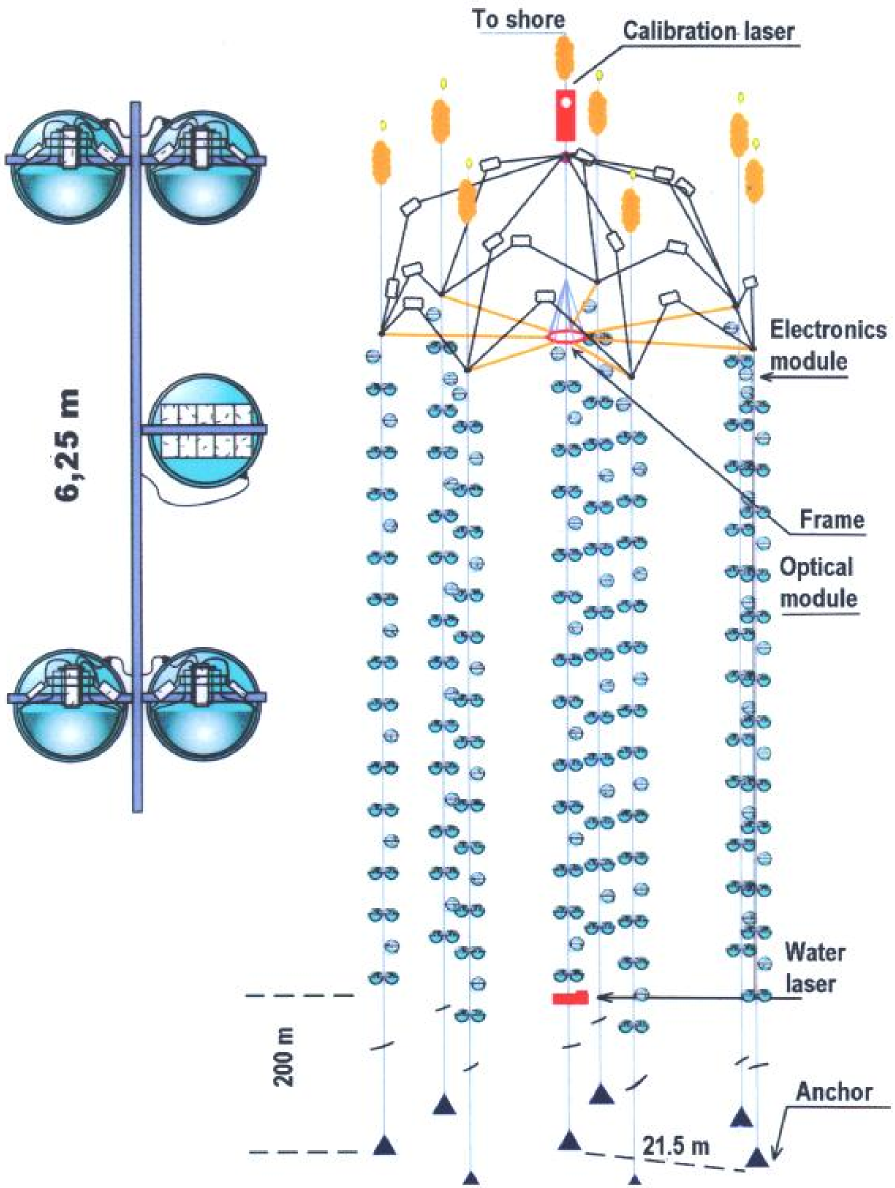
Similar geometry can be used in a water based detector deep below the sea surface (say around 4000m)

- ANTARES (Marseille)
- Nestor (Pylos, SW Pelophonysos)
- Lake Baikal
- DUMAND (Hawaii) - stoped

Problems: bioluminescence, currents, waves (during repair works)

Lake Baikal: deployment, repair works: in winter, from the ice cover

NEUTRINO TELESCOPE NT-200



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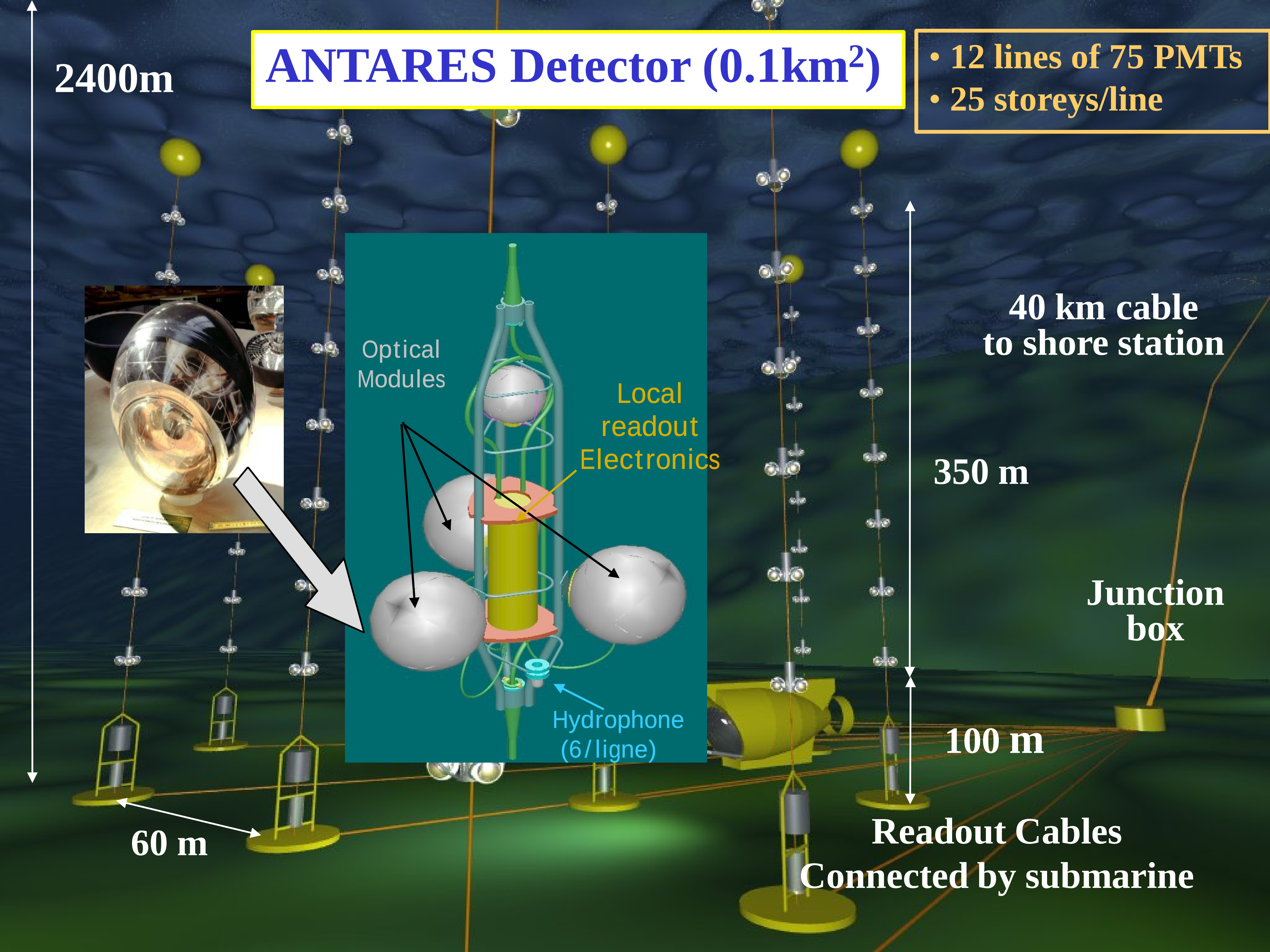
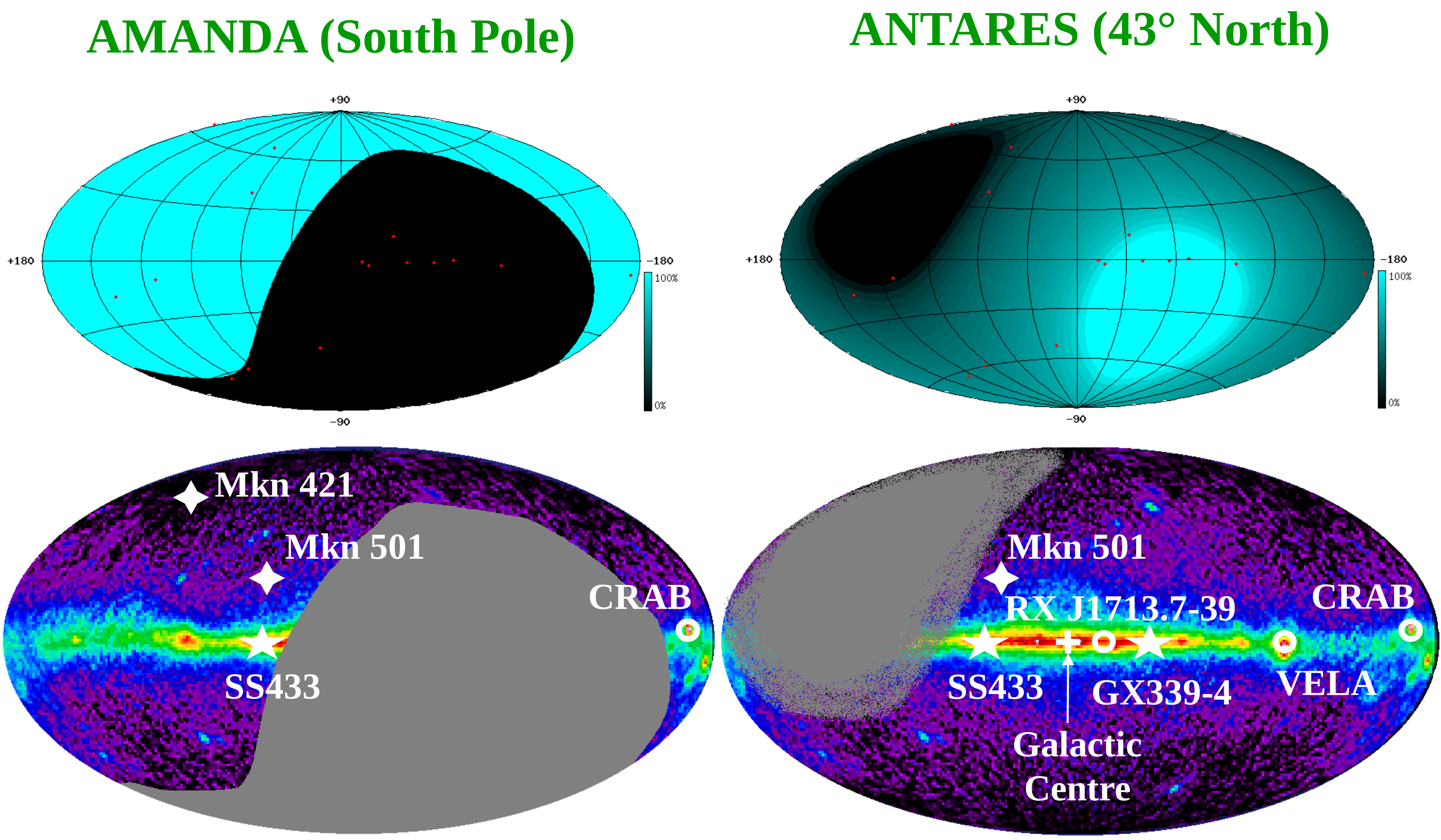


ANTARES Detector (0.1km²)
• 12 lines of 75 PMTs
• 25 storeys/line
2400m
Optical Modules
Local readout Electronics
Hydrophone (6/ligne)
40 km cable to shore station
350 m
Junction box
100 m
60 m
Readout Cables Connected by submarine

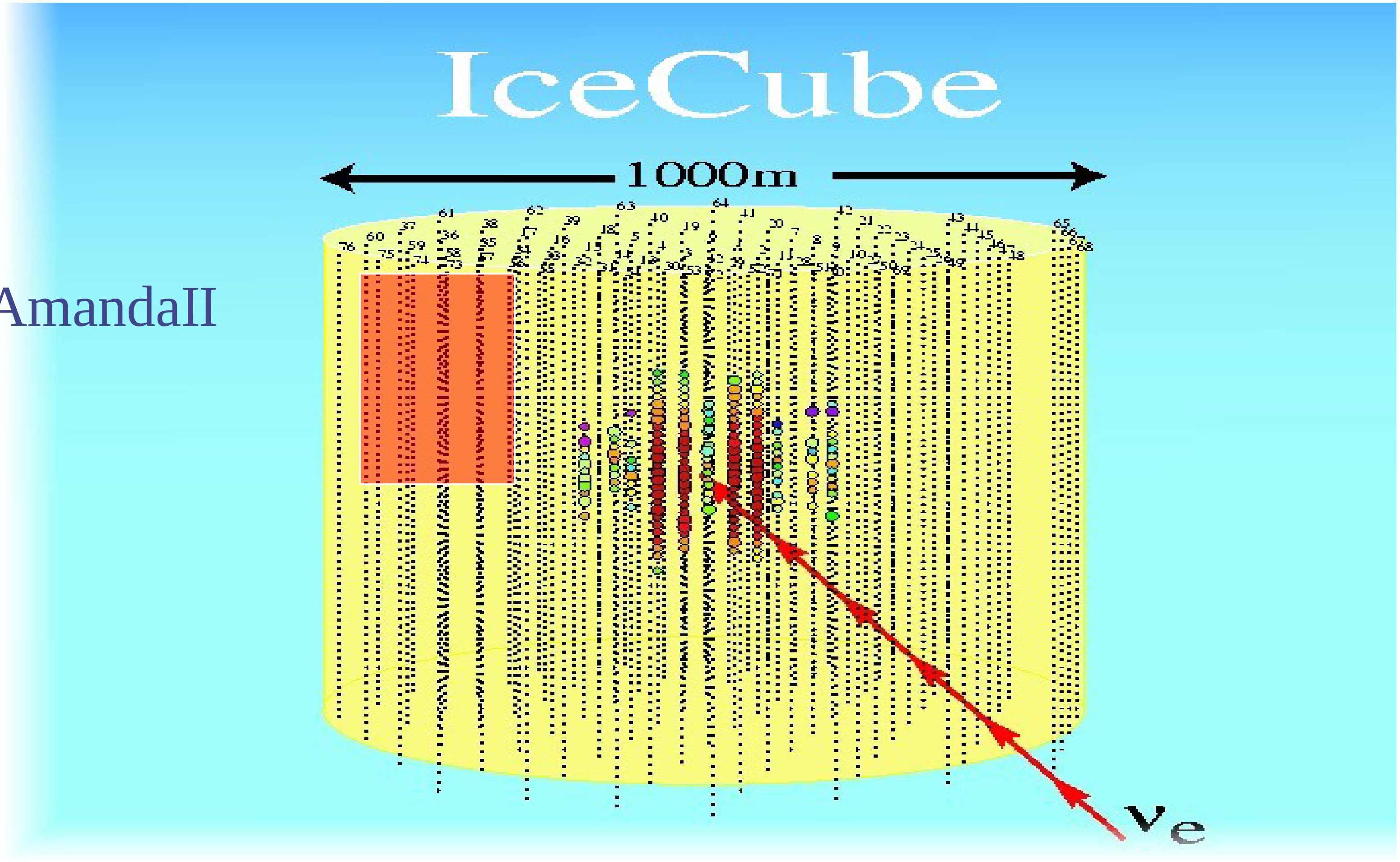
Region of sky observable by Neutrino Telescopes



Next generation neutrino telescopes

Go for 1 km^3 detector volume!

- Ice cube
- KM3



AmandaII

Additional slides

Detection of low energy neutrinos (from sun)

Solution to solar neutrino problem;

Why is the ν_e flux at the earth's surface (e.g. Homestake) ~ 1/3 that expected from models of solar ν_e production?

Do ν's oscillate:

change flavour ➔ ν_e

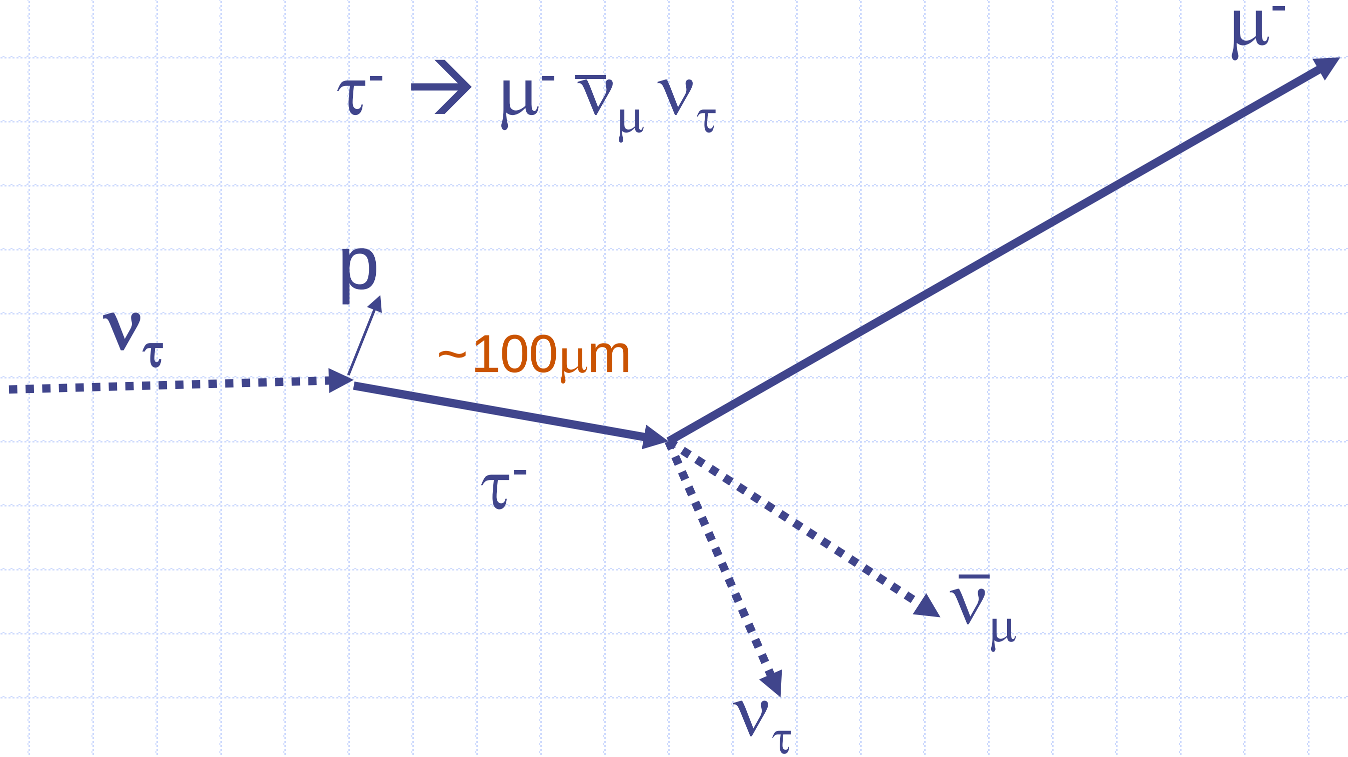
➔ ν_μ

➔ ν_τ

Detection of τ neutrinos

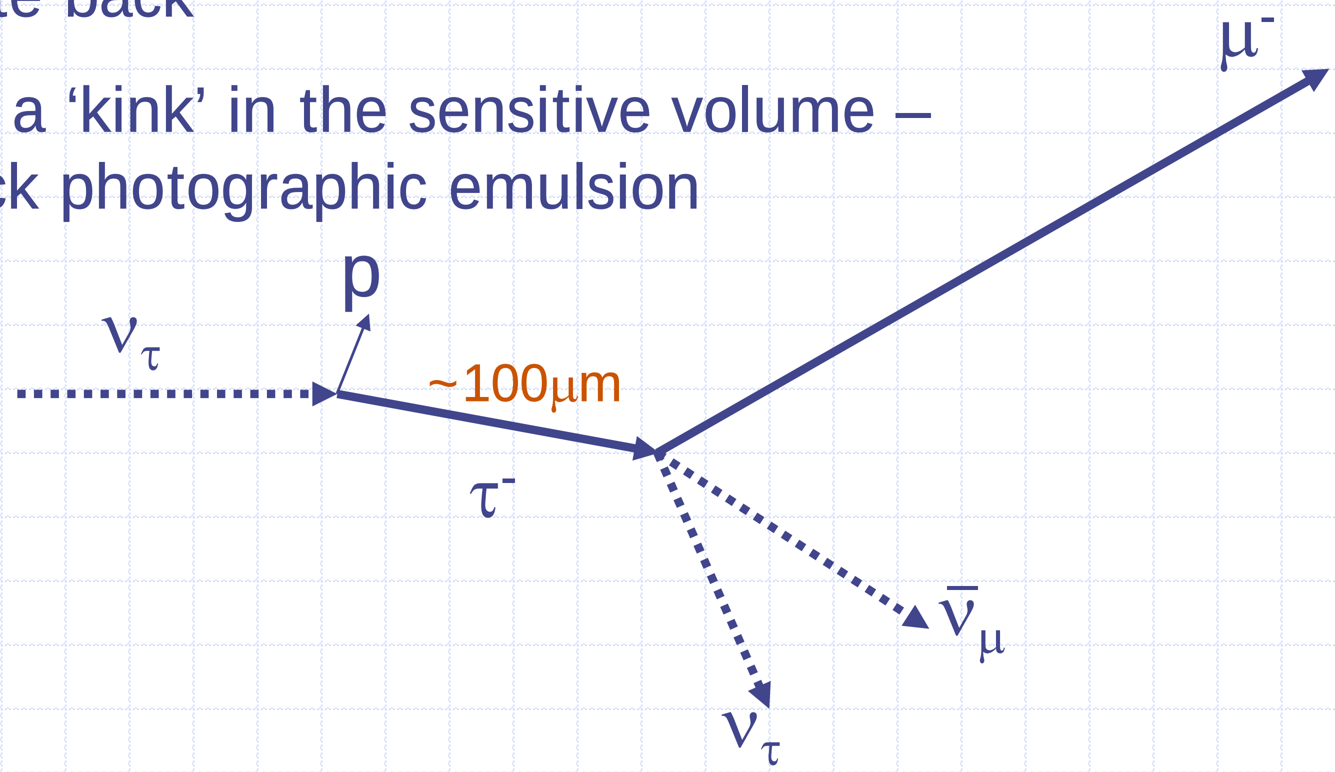
$\nu_\tau + n \rightarrow p + \tau^-$

$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$

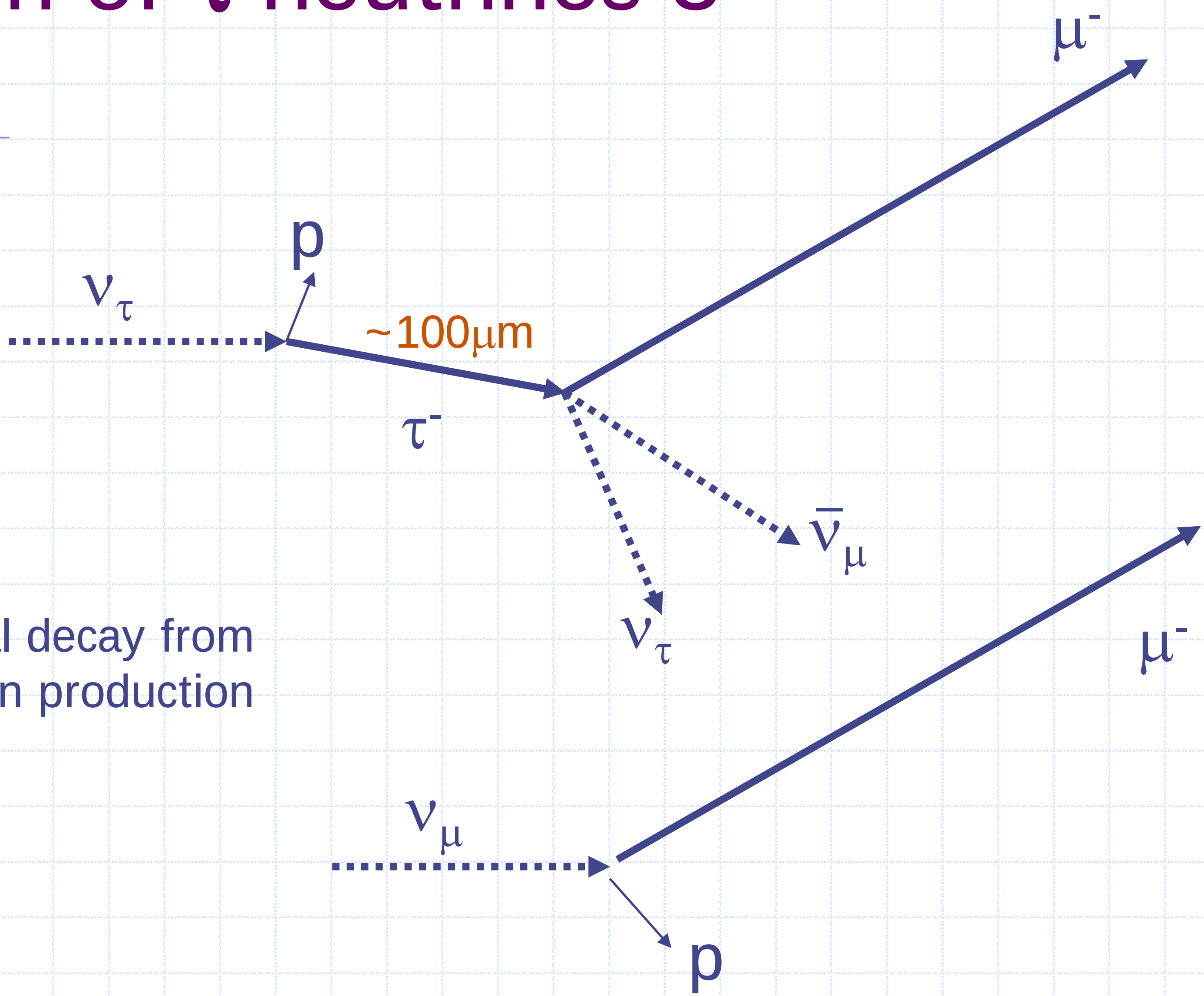


Detection of τ neutrinos 2

- Detect and identifiy mion
- Extrapolate back
- Check for a 'kink' in the sensitive volume – e.g. a thick photographic emulsion

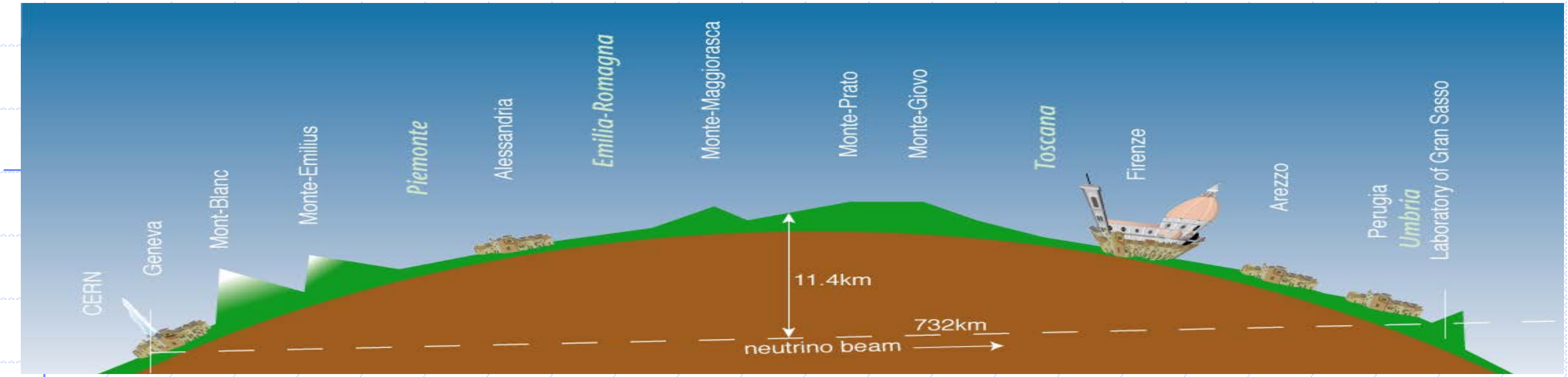


Detection of τ neutrinos 3



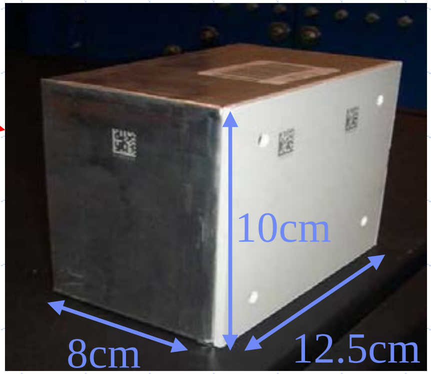
Separate signal decay from the direct muon production

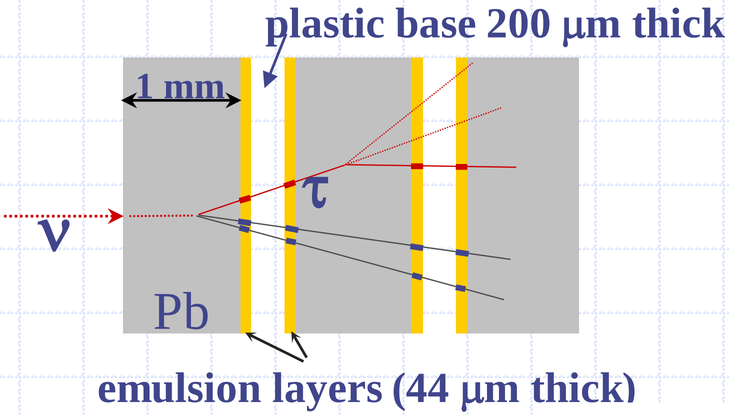
Detection of τ neutrinos: OPERA



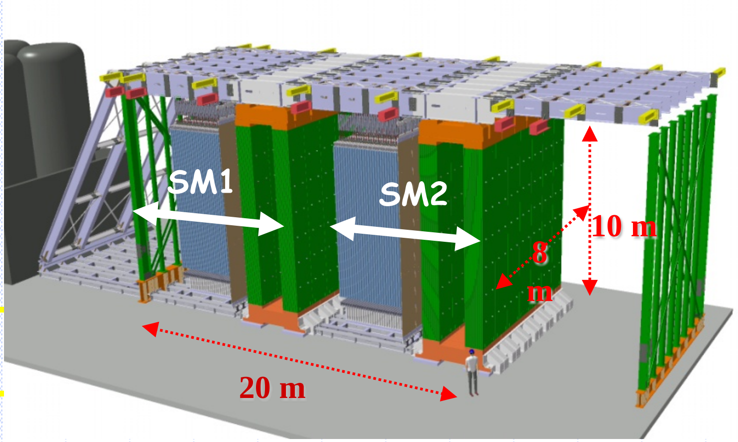
ν

8.3 kg $10X_0$





Detection unit: a brick with 56 Pb sheets (1mm) + 57 emulsion films



155000 bricks, detector total mass = 1.35 kton