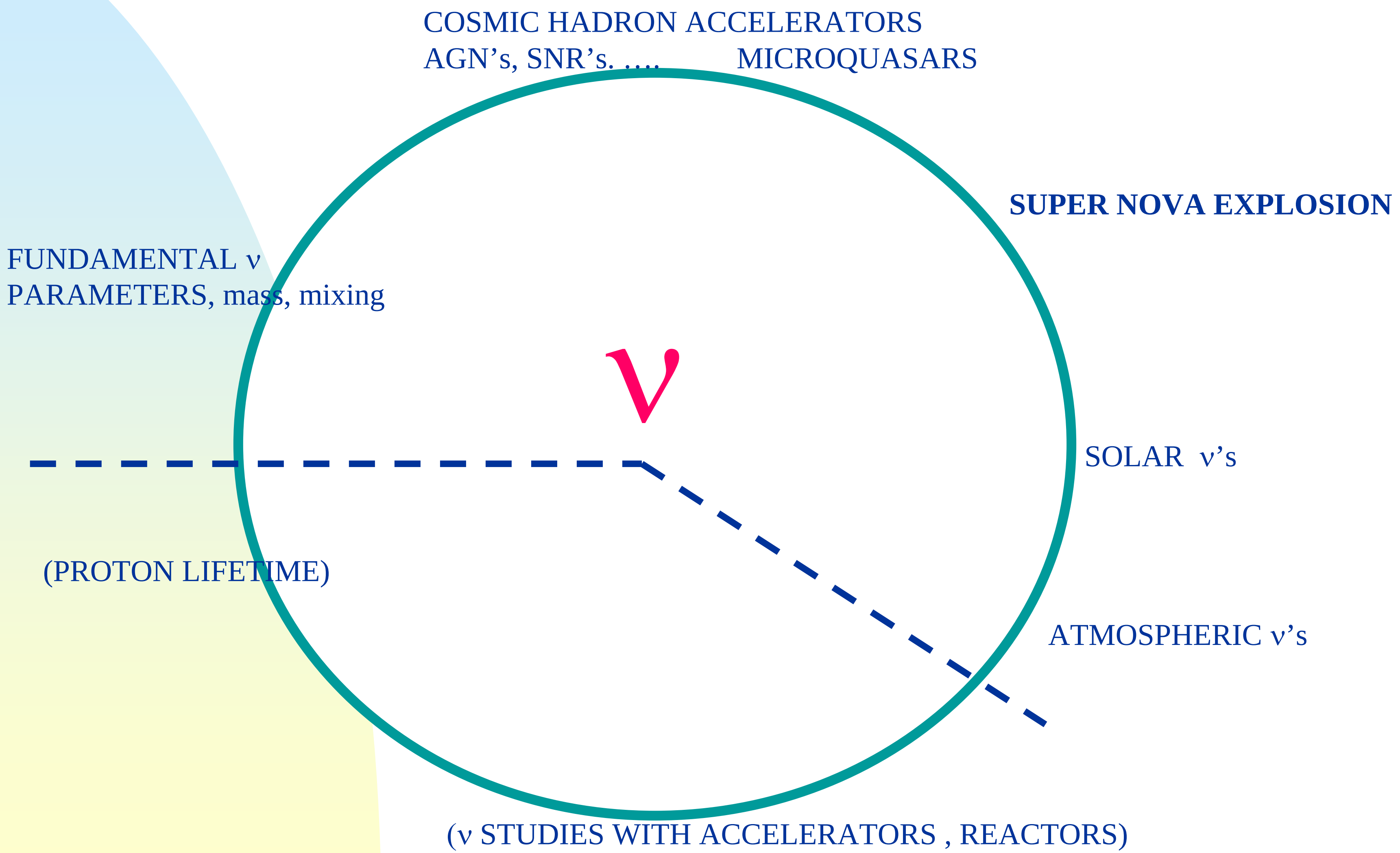
BENASQUE IV

NEUTRINO ASTRONOMY

THE PHYSICS GOALS

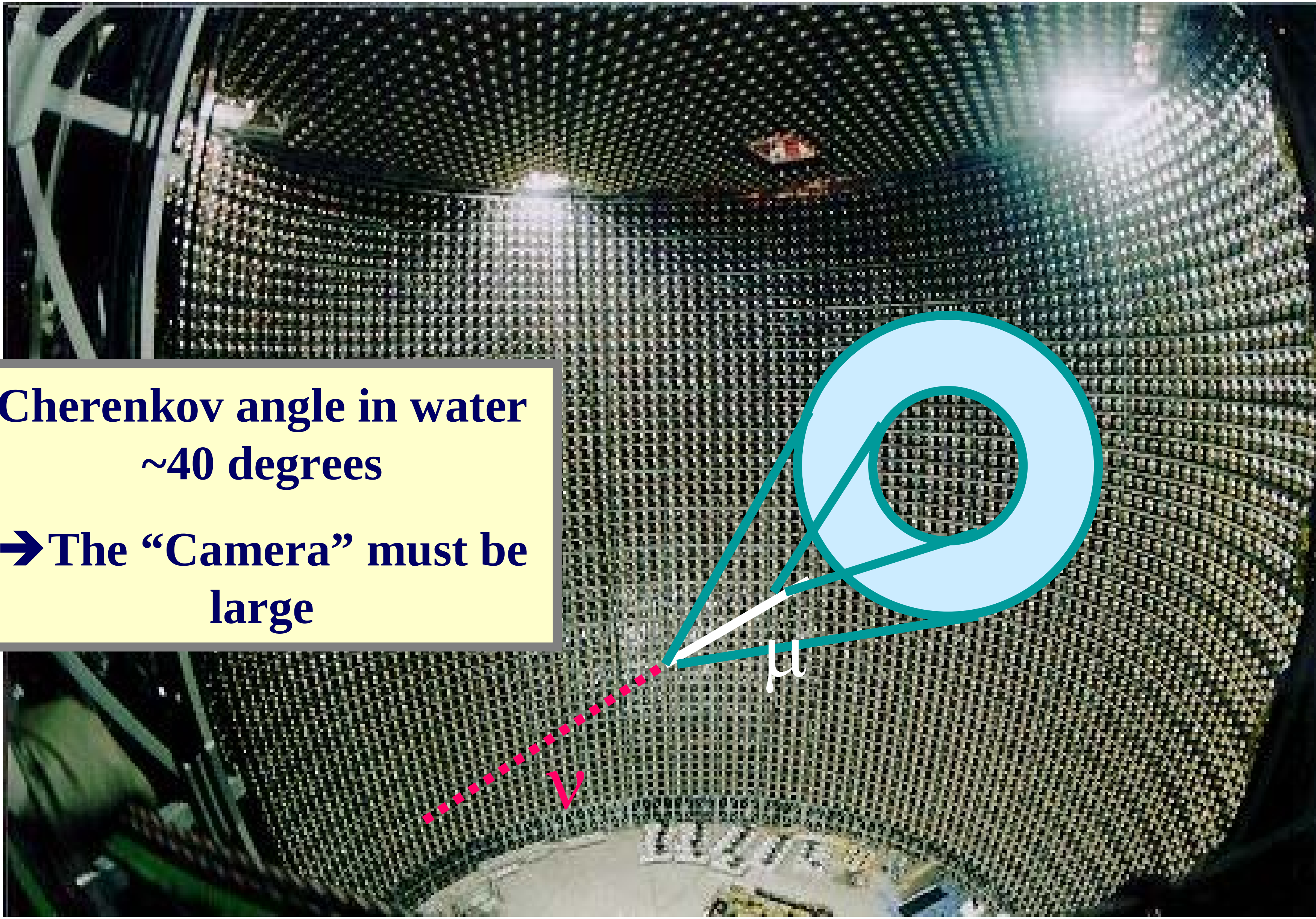
(large ν detectors)



REQUIREMENTS, PROBLEMS OF ν-DETECTION FROM COSMIC SOURCES

- ULTRA-LARGE DETECTOR VOLUMES NEEDED
  RATES NEVERTHELESS VERY SMALL
- INDIRECT DETECTION THROUGH NEUTRAL /CHARGED CURRENT REACTIONS
- USE OF CHERENKOV LIGHT IN LARGE WATER VOLUMES
- SCINTILLATION LIGHT IN LARGE LIQUID SCINTILLATOR DETECTORS
- SHIELDING PROBLEMS -> DETECTORS DEEP UNDERGROUND
  FOR LOWER ENERGY: NEED OF LOW BACKGROUND MATERIALS
- DUE TO EARTH ROTATION 4π LIGHT DETECTOR COVERAGE
- CALIBRATION A PROBLEM
- DETECTORS ALSO USEFUL FOR OTHER FUNDAMENTAL PHYSICS STUDIES

THE TEMPLATE DETECTOR FOR ALL LARGE VOLUME WATER DETECTORS SUPERKAMIOKANDE

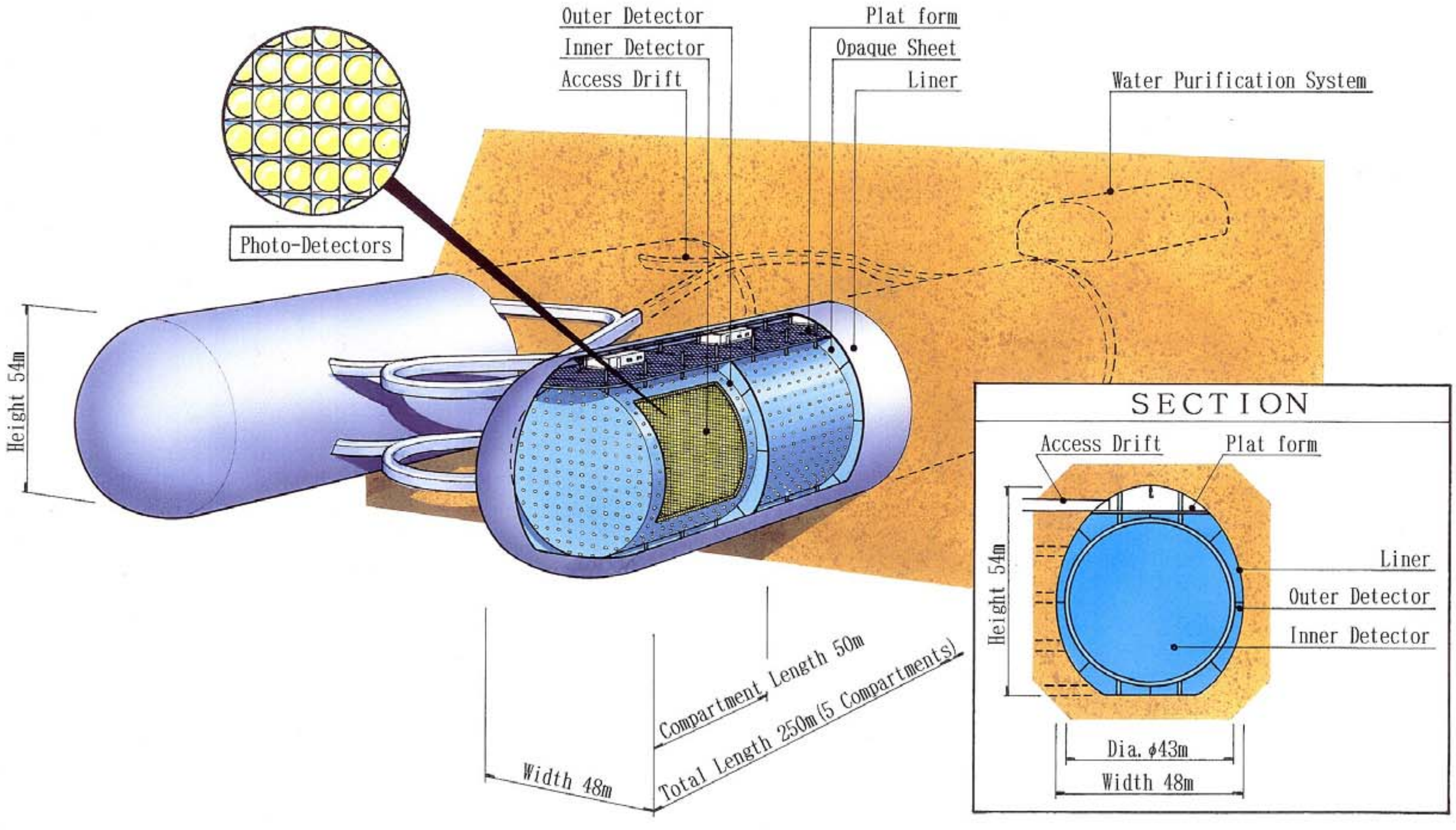


Cherenkov angle in water ~40 degrees

➔The "Camera" must be large

Hyper-Kamiokande

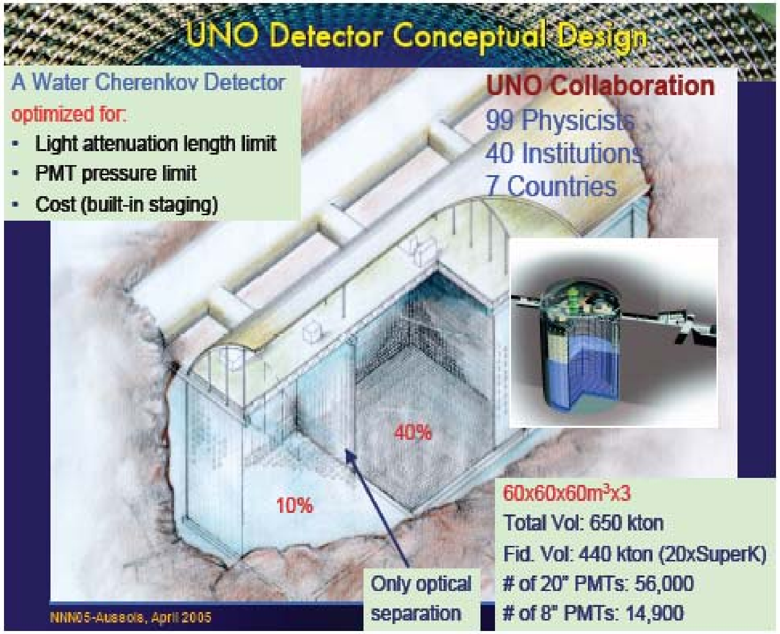
1 Mton water Cherenkov detector at Kamioka



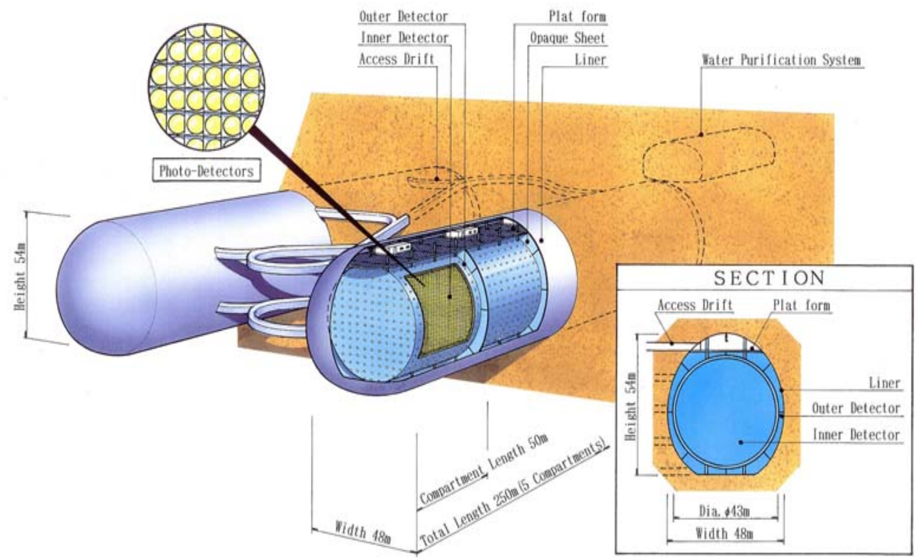
Comparison of 3Generations of Kamioka Nucleon Decay Experiments

	Kamiokande	Super-Kamiokande	Hyper-Kamiokande
Mass	3,000 t (+1,500 t)	50,000 t	1,000,000 t
Photosensitive Coverage	20 %	40 % (SK-I and -III) 20 % (SK-II)	?
Observation Started	1983	1996	?
Cost (Oku-Yen)*	5	100	500?**

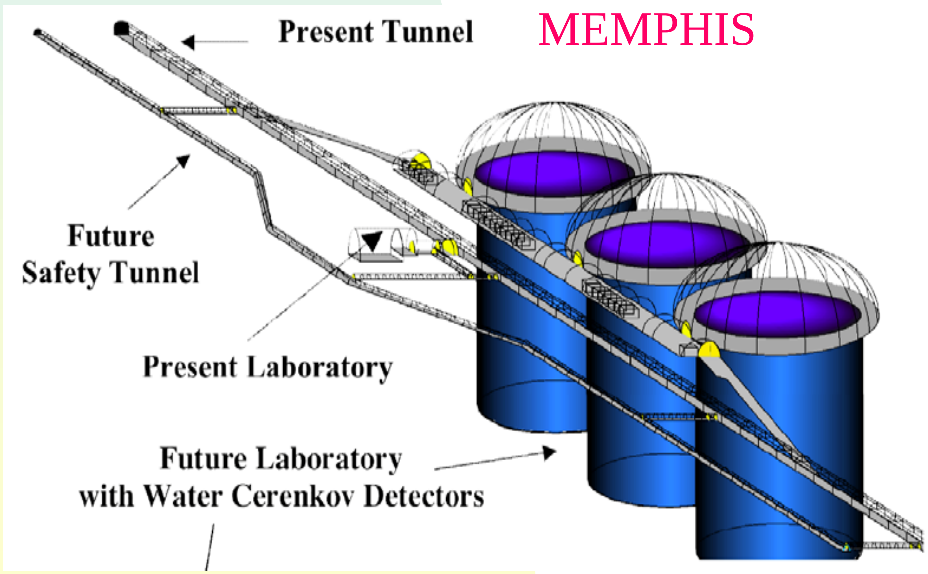
* 1 Oku-Yen ≈ 1M$
** Target cost; No realistic estimate yet



HYPER KAMIOKANDE



MEMPHIS



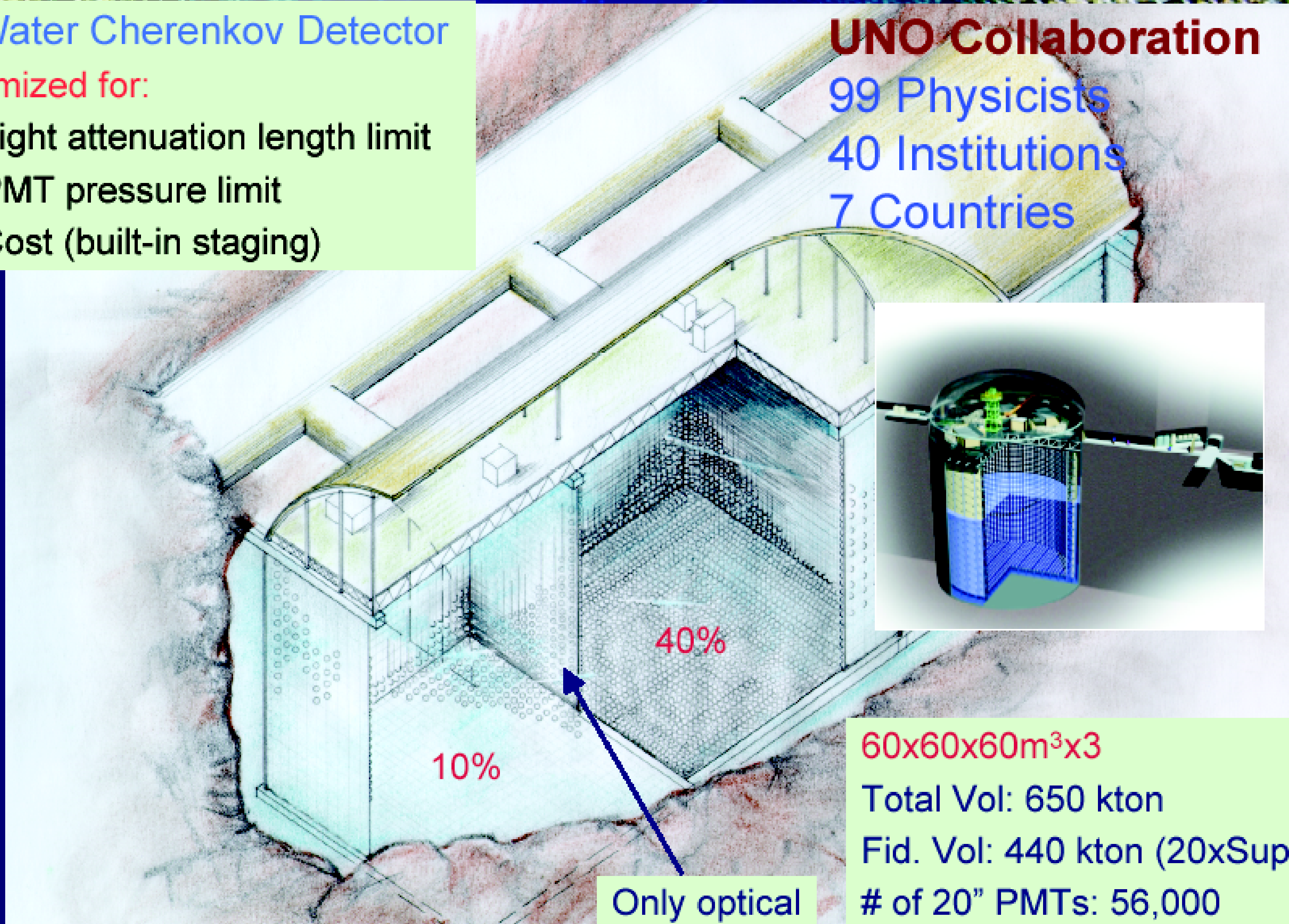
- DUE and TRE have a choice to put Gd in one module in order to enhance the sensitivity to low-energy antineutrino detection.
- See, an interesting talk by Vagins on GADZOOKS

UNO Detector Conceptual Design

A Water Cherenkov Detector
optimized for:

- Light attenuation length limit
- PMT pressure limit
- Cost (built-in staging)

UNO Collaboration
99 Physicists
40 Institutions
7 Countries

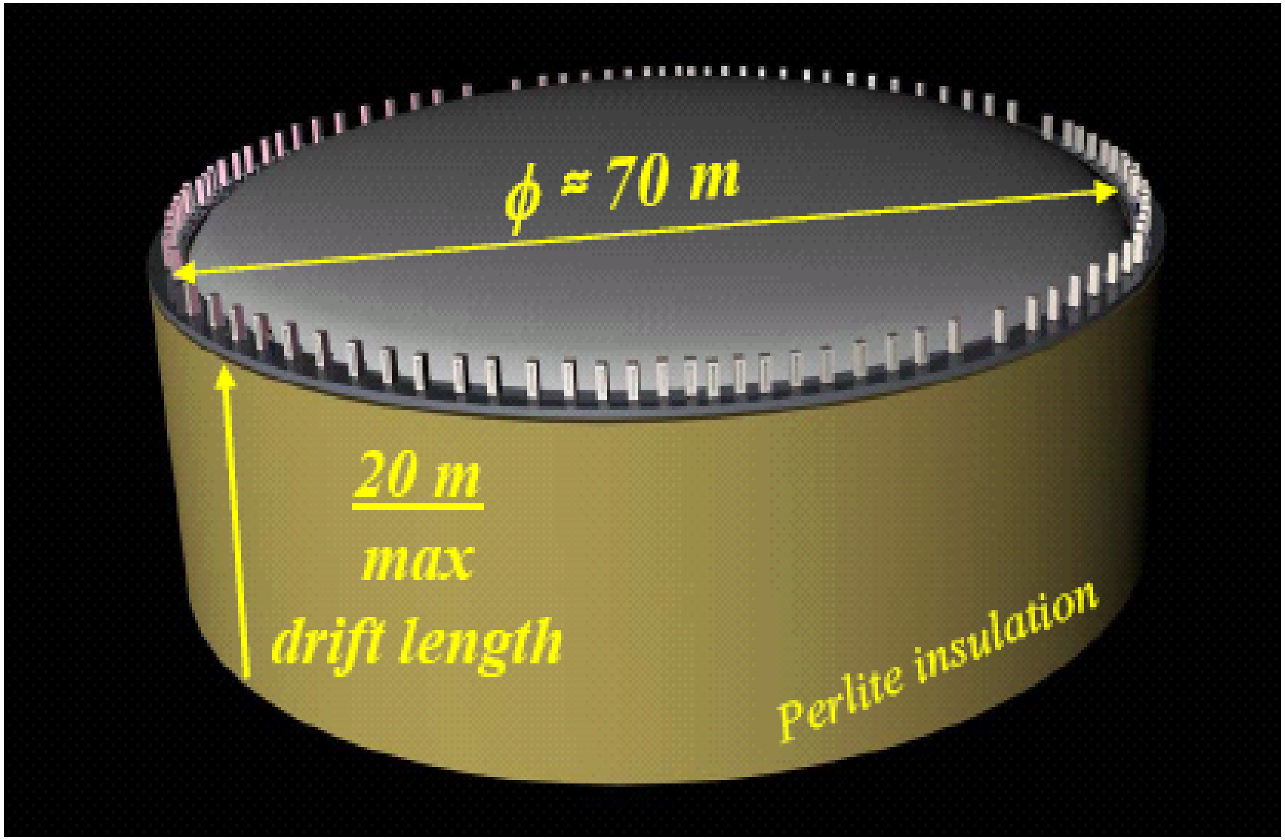


Only optical separation

$60 \times 60 \times 60 m^3 \times 3$
Total Vol: 650 kton
Fid. Vol: 440 kton (20xSuperK)
# of 20” PMTs: 56,000
# of 8” PMTs: 14,900

Next generation 100 kton liq. Ar detector

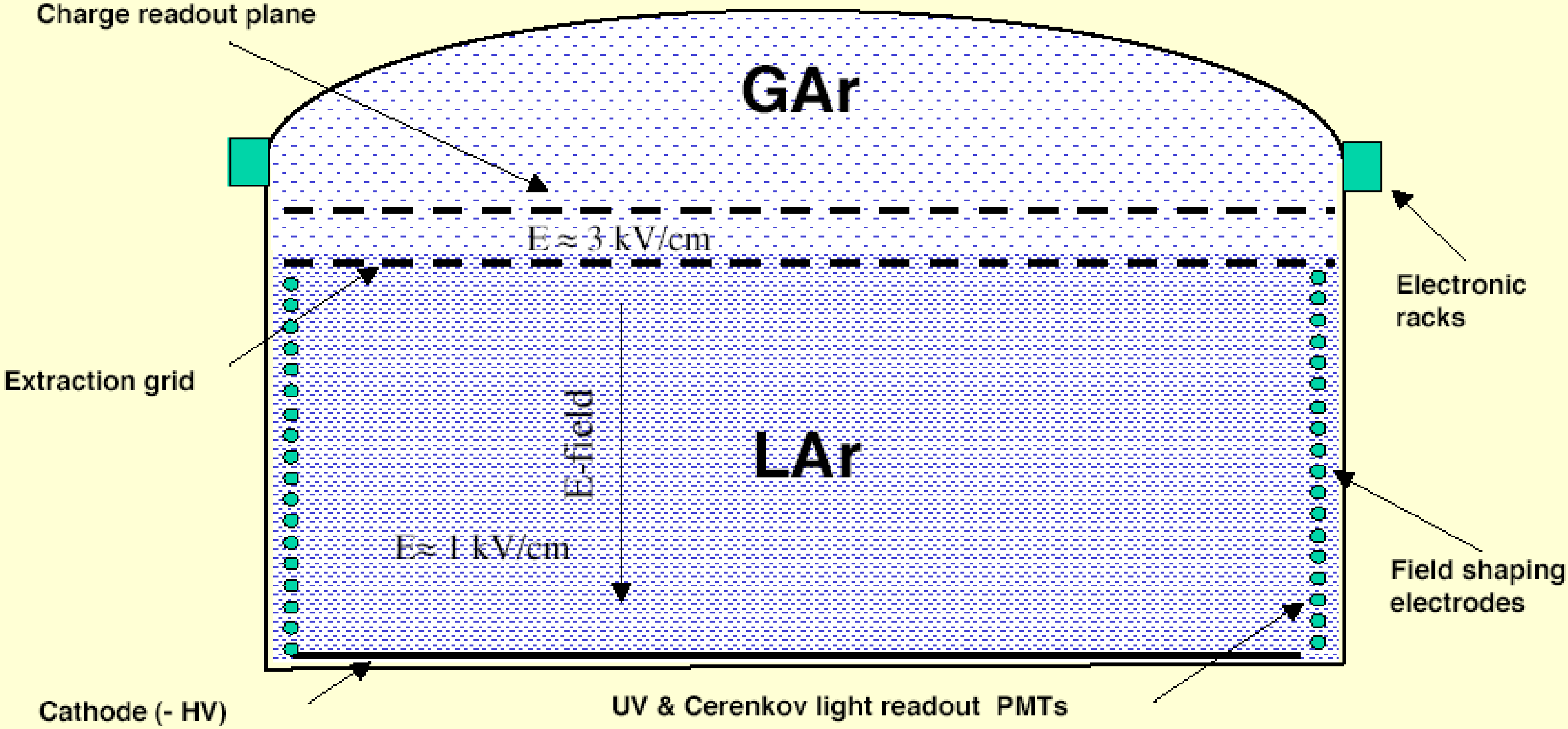
Rubbia



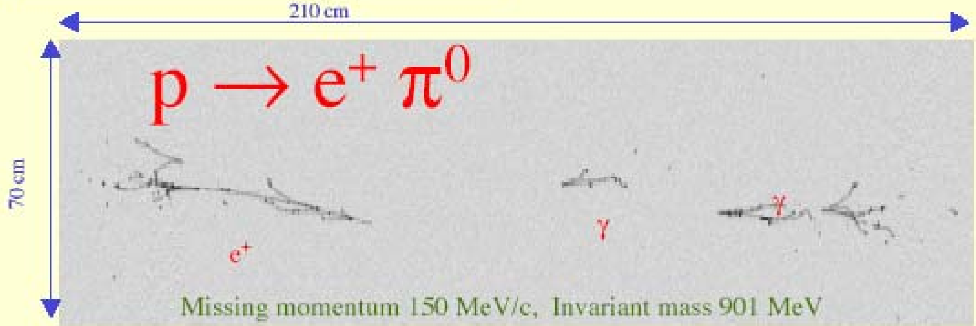
A tentative detector layout

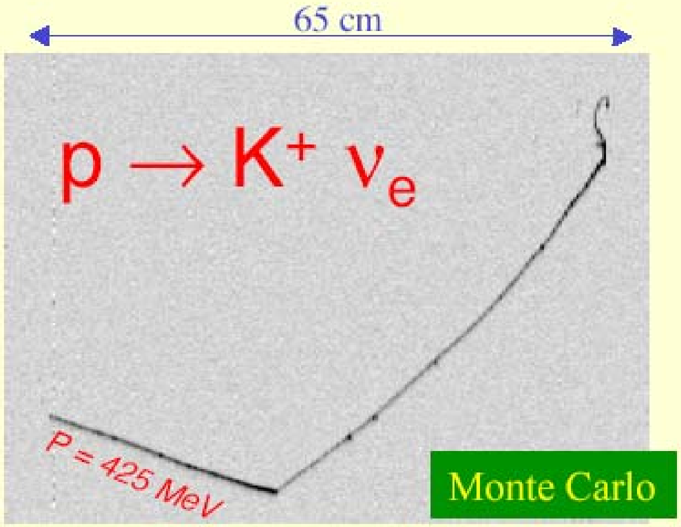
Single detector: charge imaging, scintillation, Cerenkov light

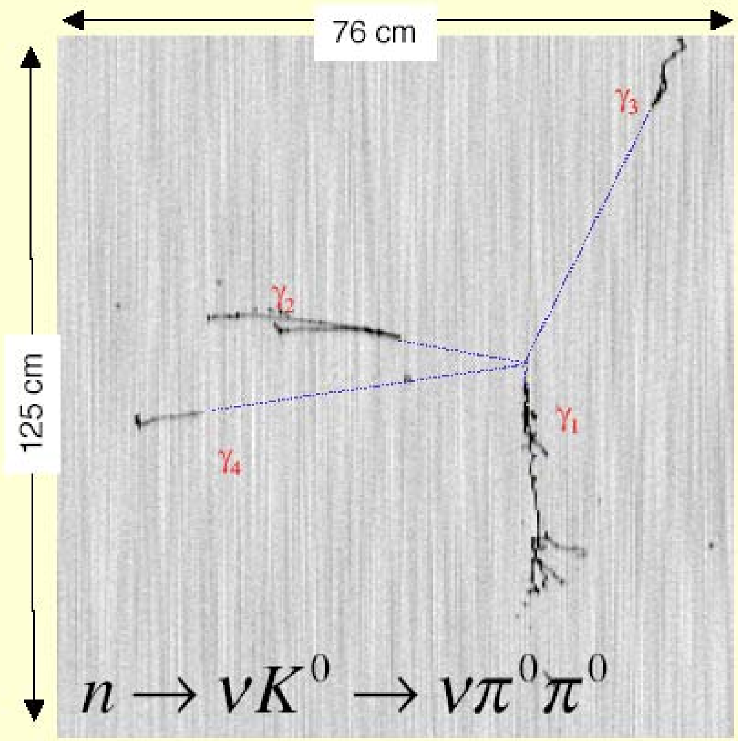
Dewar	$\phi \approx 70$ m, height ≈ 20 m, perlite insulated, heat input ≈ 5 W/m^2
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m^3, ratio area/volume $\approx$ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc $\phi \approx 70$ m located in gas phase above liquid phase
Charge readout electronics	100000 channels, 100 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 1000 immersed 8" PMTs with WLS
Visible light readout	Yes (Cerenkov light), 27000 immersed 8" PMTs of 20% coverage, single γ counting capability



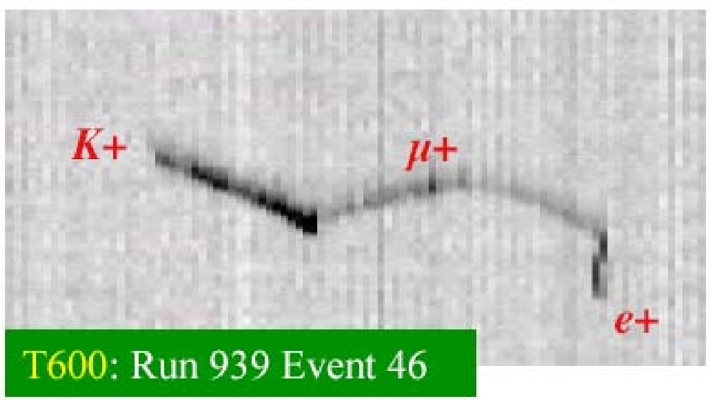
Nucleon decay



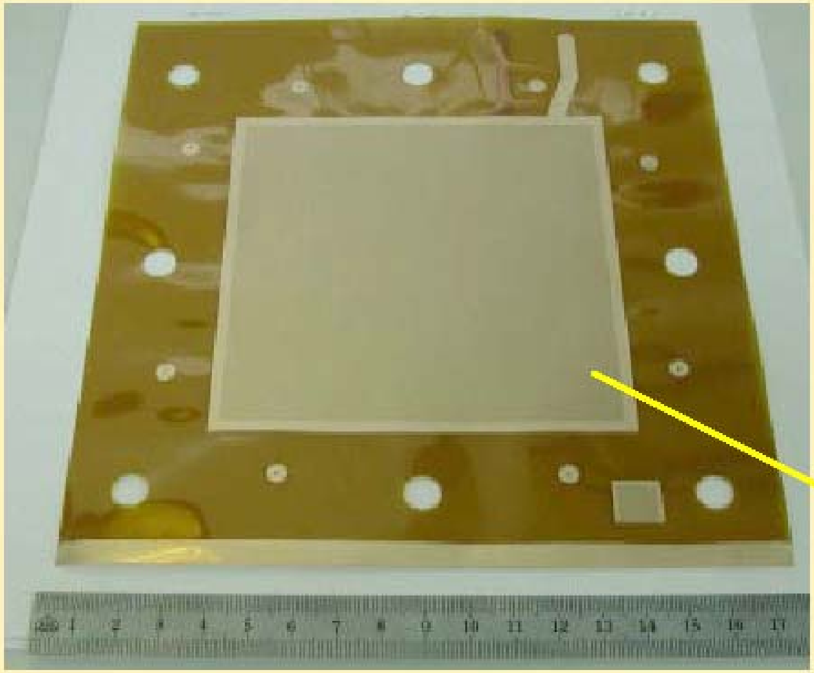


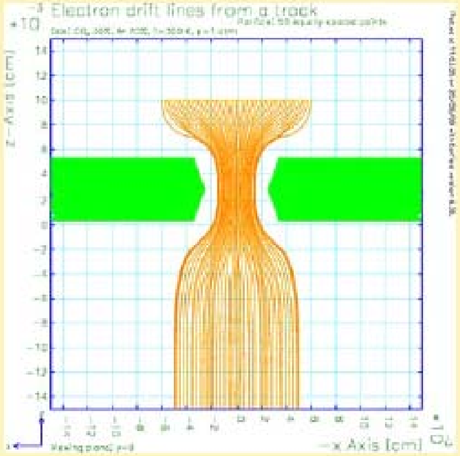


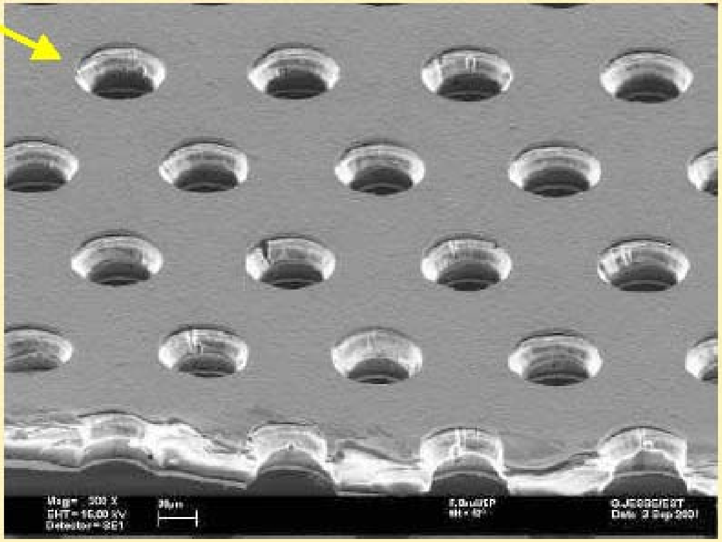
"Single" event detection capability



Gas Electron Multiplier GEM (F. Sauli et al., CERN)







100x100 mm²

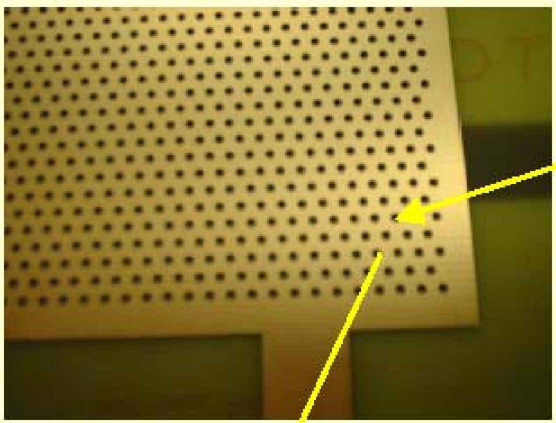
A gas electron multiplier (GEM) consists of a thin, metal-clad polymer foil, chemically pierced by a high density of holes. On application of a difference of potential between the two electrodes, electrons released by radiation in the gas on one side of the structure drift into the holes, multiply and transfer to a collection region.

Thick Large Electron Multiplier (LEM)

Thick-LEM (vetronite Cu coated + holes)

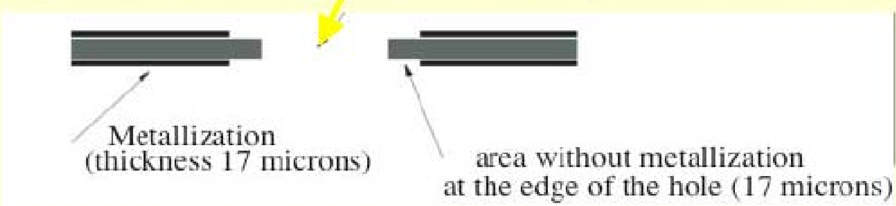
Sort of macroscopic GEM

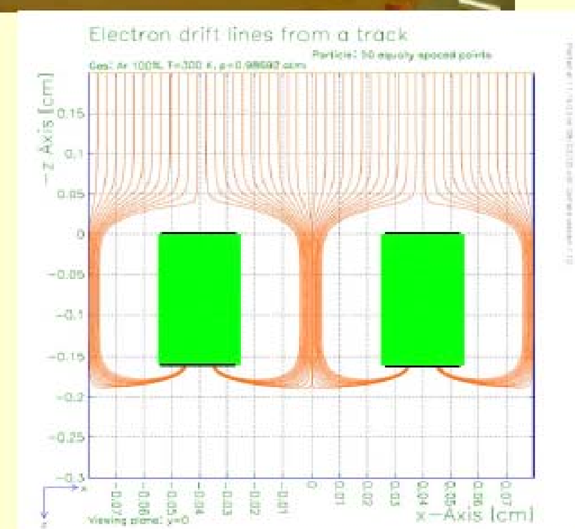
A priori more easy to operate at cryogenic temperature



•Three thicknesses:
1, 1.6 and 2.4 mm

•Amplification hole diameter = 500 μm



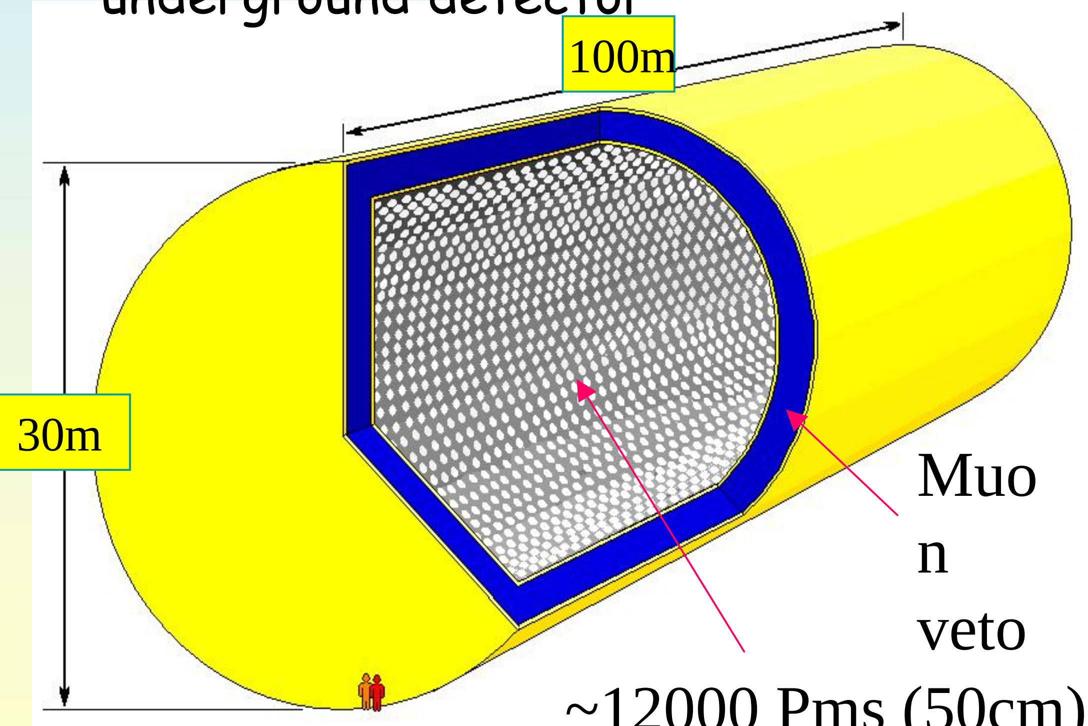


Next-generation liq. Scintillator detector

Possible locations

LENA

A large (50 kton) liquid scintillator underground detector



CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE

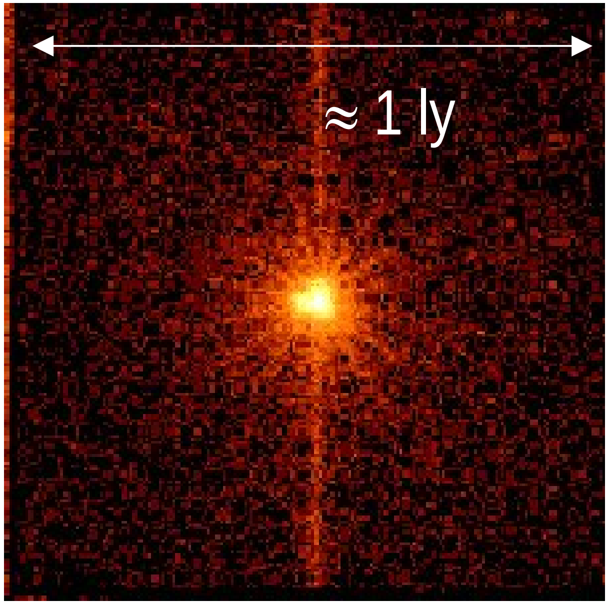
DETECTORS FOR HIGH ENERGY ν ASTRONOMY

E> 100 GeV

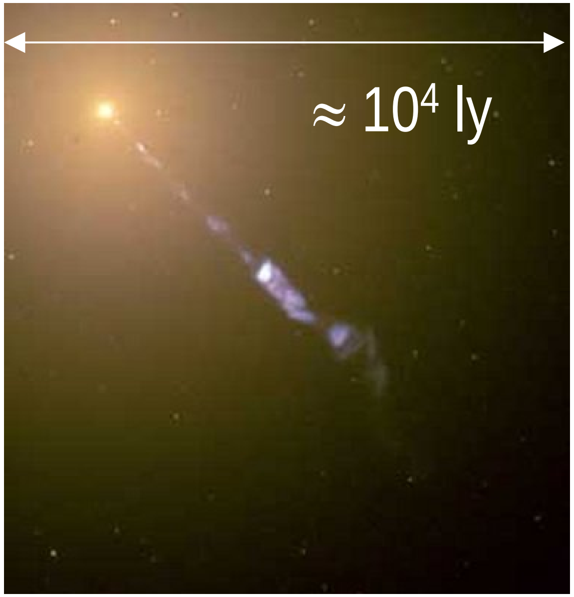
Possible neutrino point sources:

Supernova remnant
(Crab nebula)

Microquasar
(SS433 etc.)



Active Galaxy
(e.g. M87)



galactic

extra-galactic

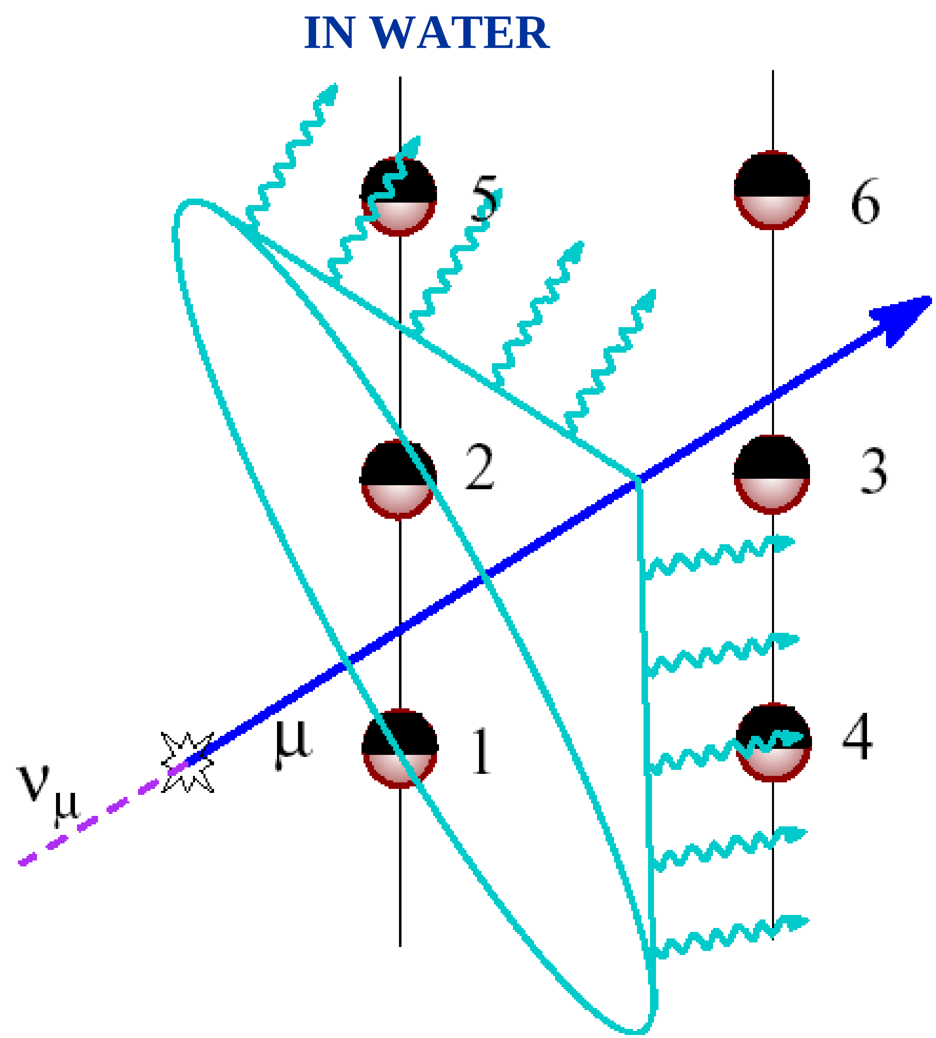
Physics motivation

- Astrophysics
  - VHE Neutrino astronomy
  - Composition of jets
  - Engine of cosmic accelerators
- Particle physics
  - Origin of UHE cosmic rays
  - Massive particles (GUT)
  - Dark matter
  - Neutrino properties (ν_τ, σ)

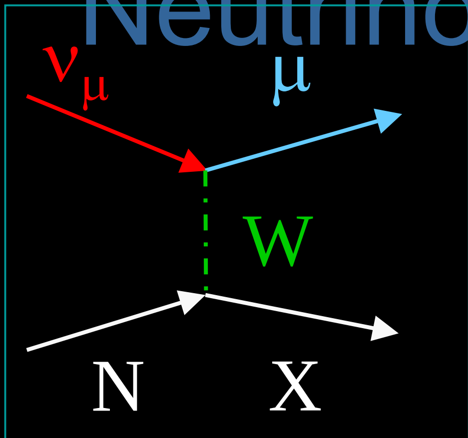
Detection Method for ν_μ

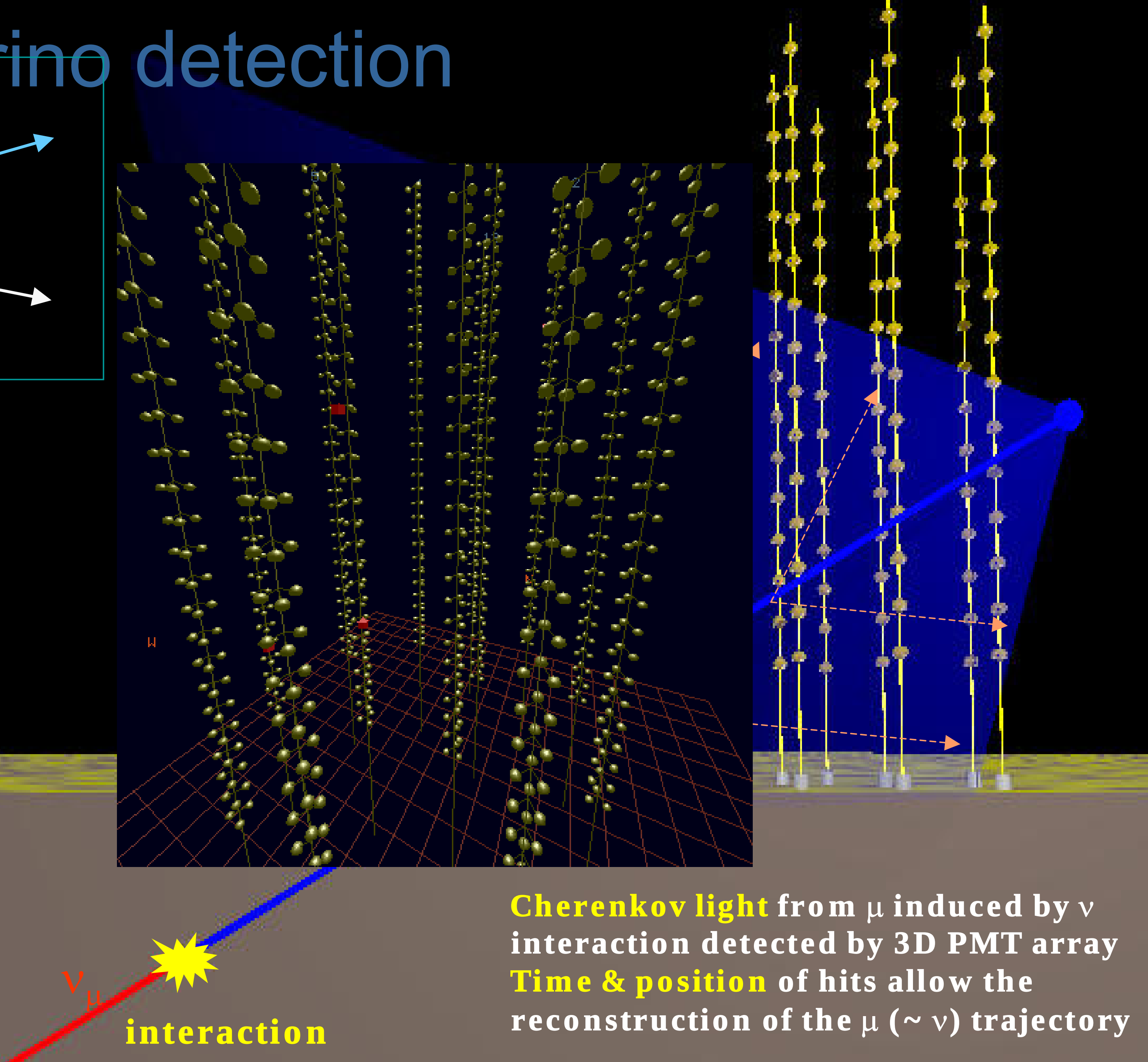
- Cherenkov photons are detected by array of PMTs

- Tracks are reconstructed by *maximum likelihood* method of photon arrival times.



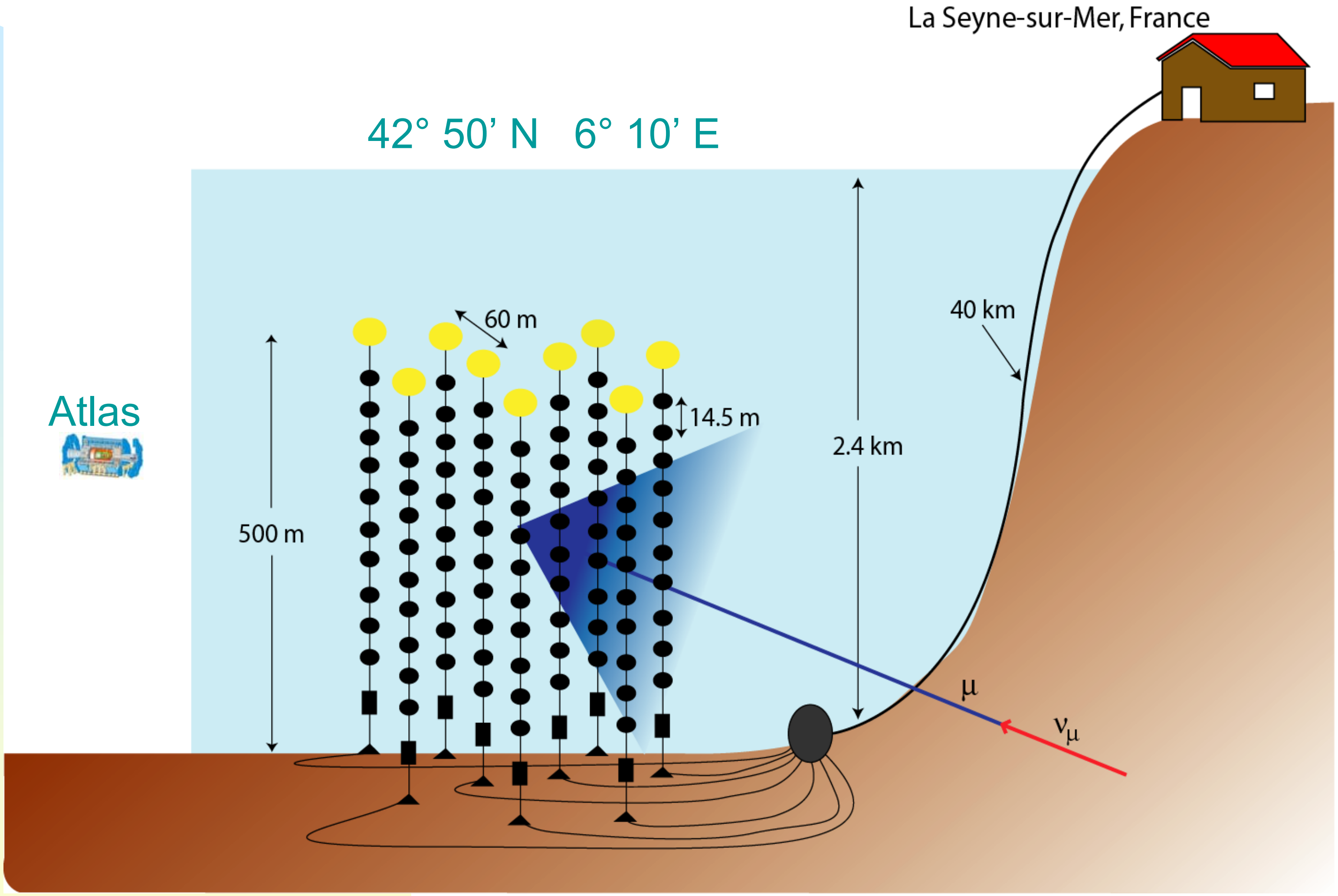
Neutrino detection



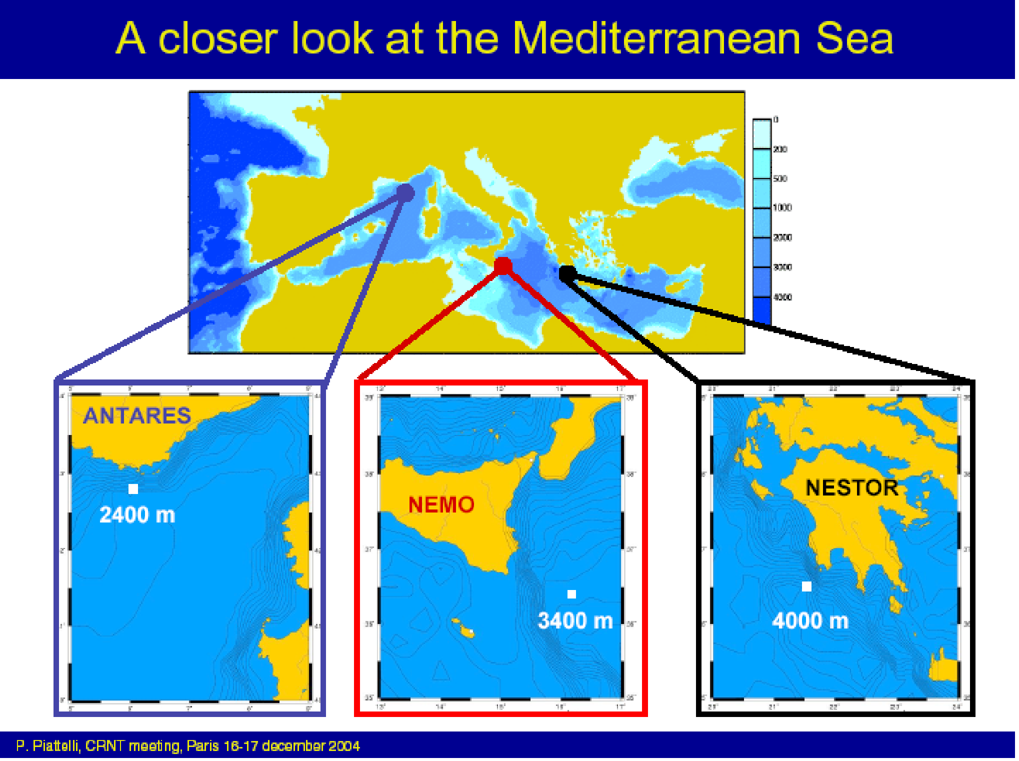


Cherenkov light from μ induced by ν interaction detected by 3D PMT array
Time & position of hits allow the reconstruction of the μ (~ ν) trajectory

Antares detector



Equipped volume 0.1 km^2 x 0.4 km (=800 x SuperK)



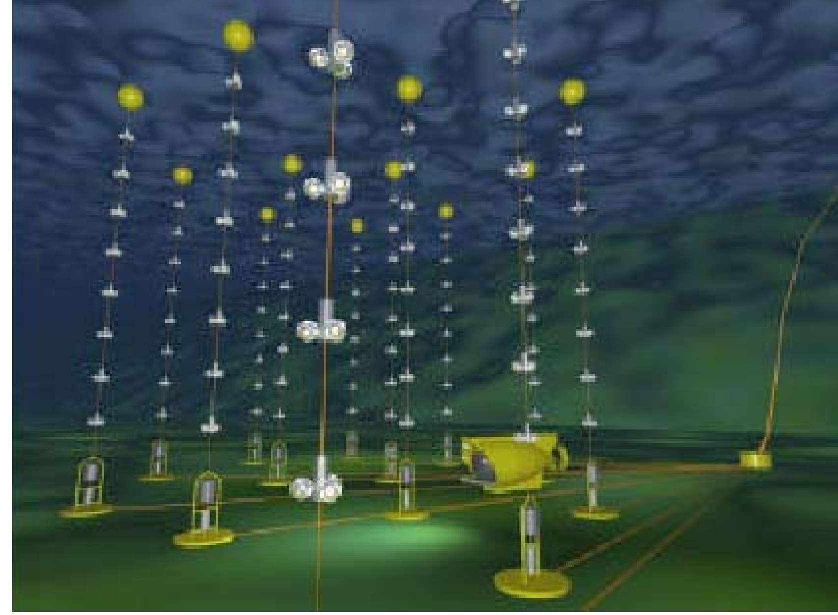


Fig. 17. Layout of the ANTARES array.

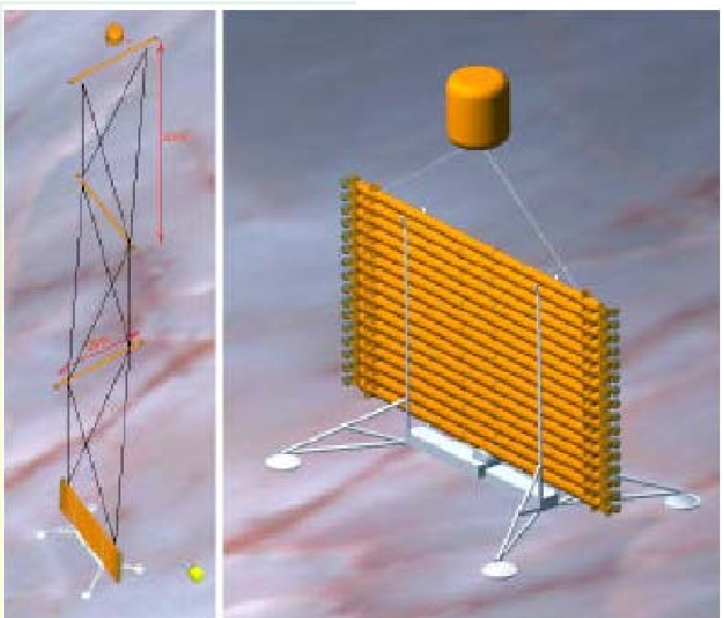
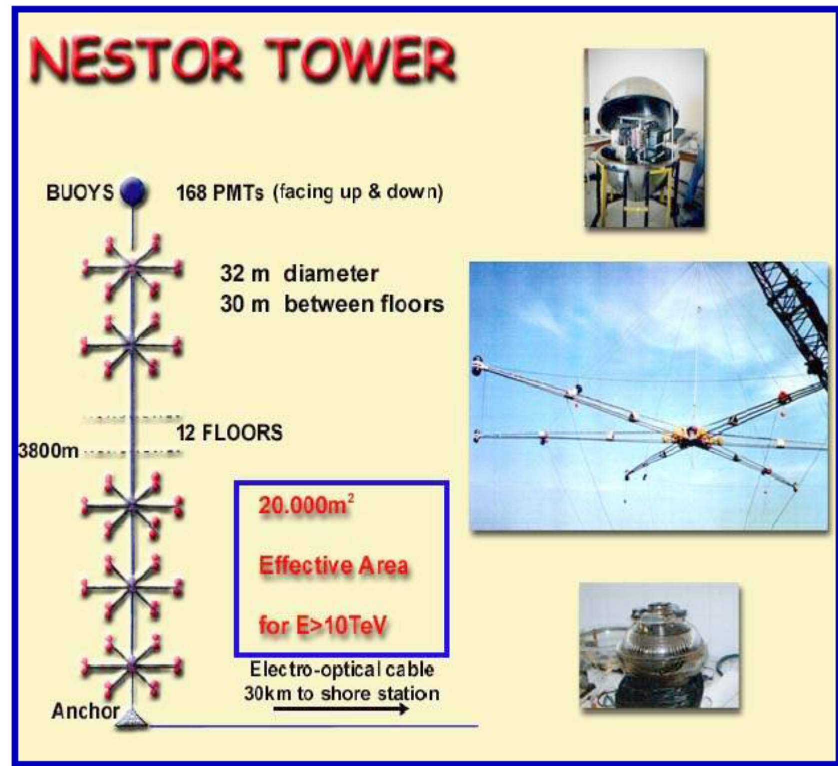


Fig. 18 Concept for a NEMO Tower



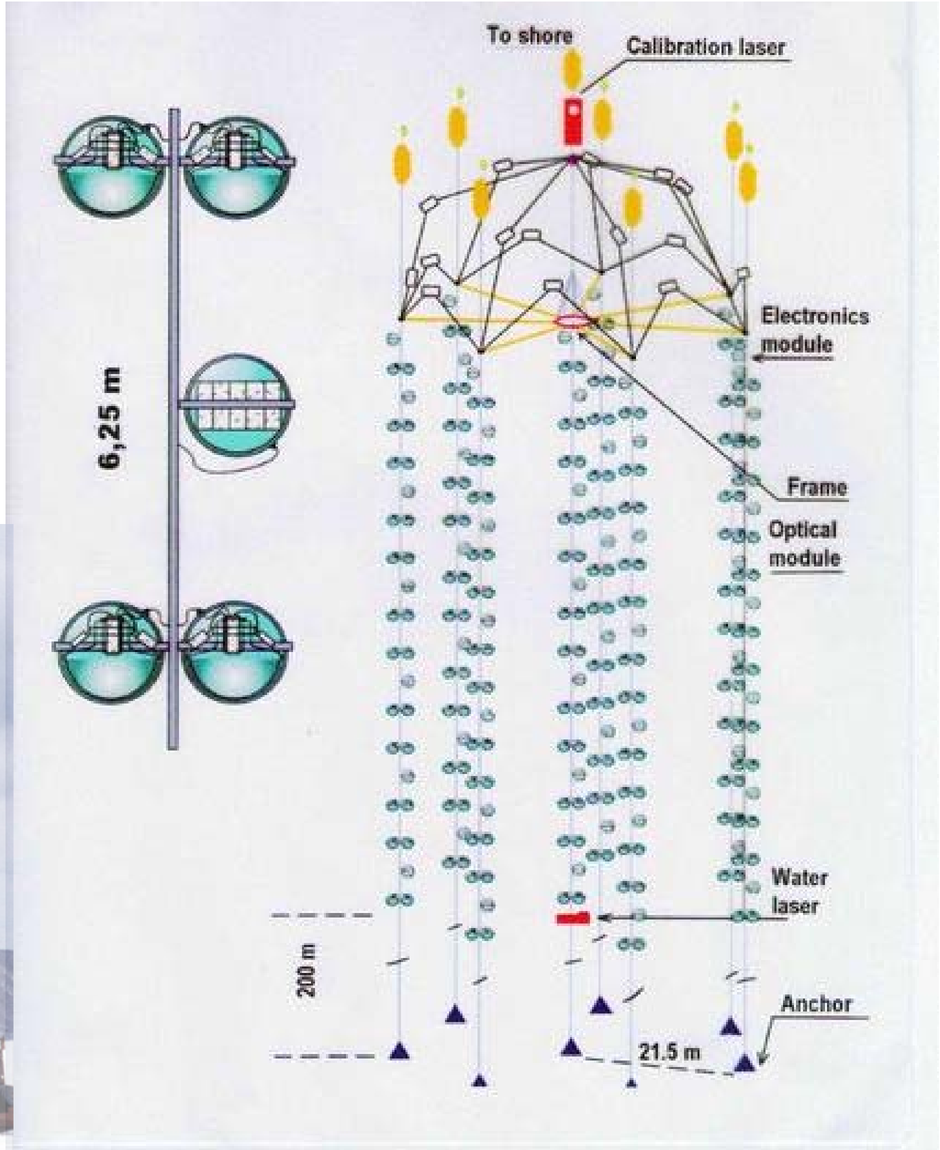
Neutrino Telescopes

BAIKAL NT-200

Baikal NT-200

Location: Lake Baikal	
Commissioned:	1997
No. of Strings:	8
Optical Sensors:	192
Depth:	1100m
Instrum. Volume/km3:	10^{-4}
μ-Effective area (1 TeV):	≈2000 m^2
Angular resolution (1 TeV):	3°

Deployment and maintenance:
From frozen surface in winter.



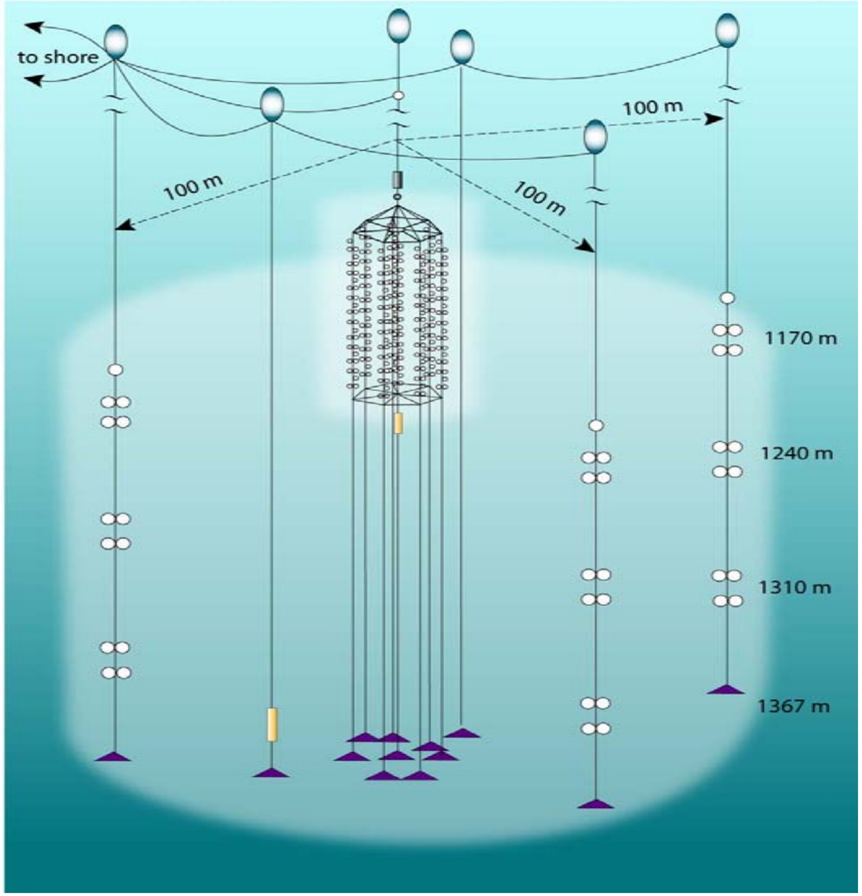
Neutrino Telescopes BAIKAL NT200+

Baikal upgrade:
NT-200+
Commissioned: April 2005

Addition of
3 outer strings 12 PMT each
Other improvements: DAQ, new cable to shore,…

Increase in sensitivity by factor 3-4.

Preparing a design for: Giant Volume Detector, km scale



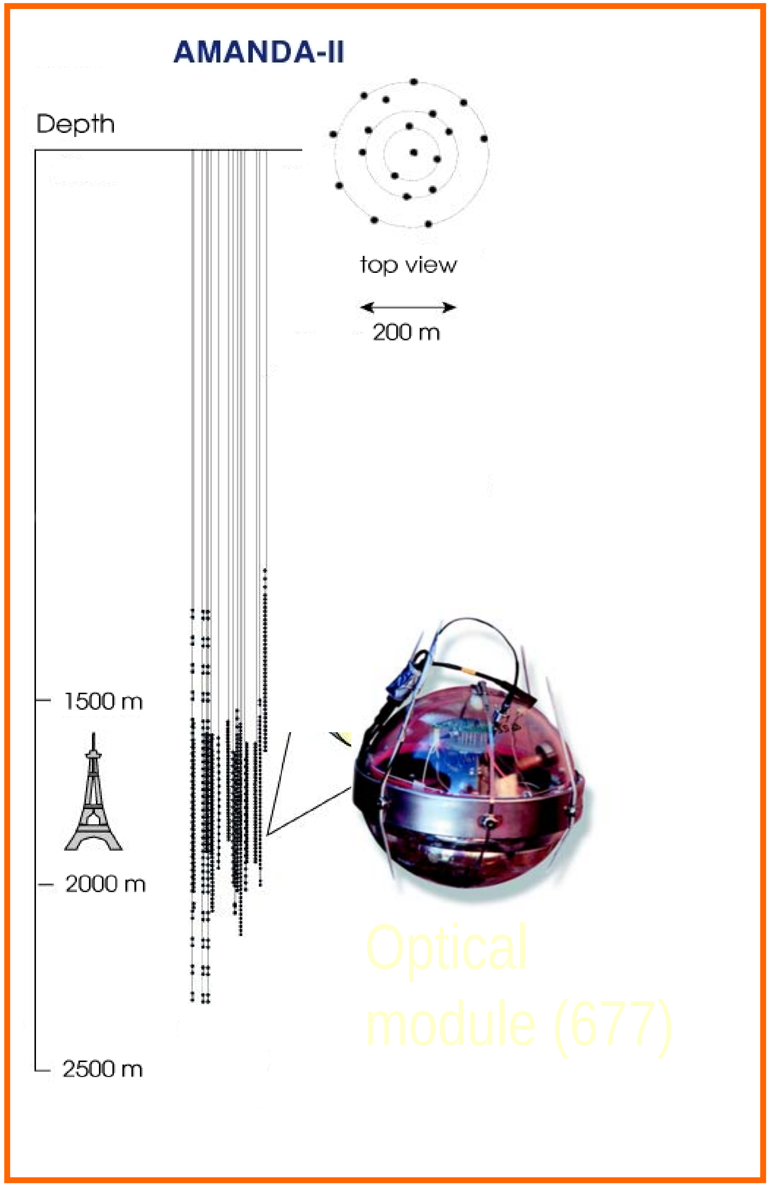
Neutrino Telescopes — AMANDA-II

AMANDA-II

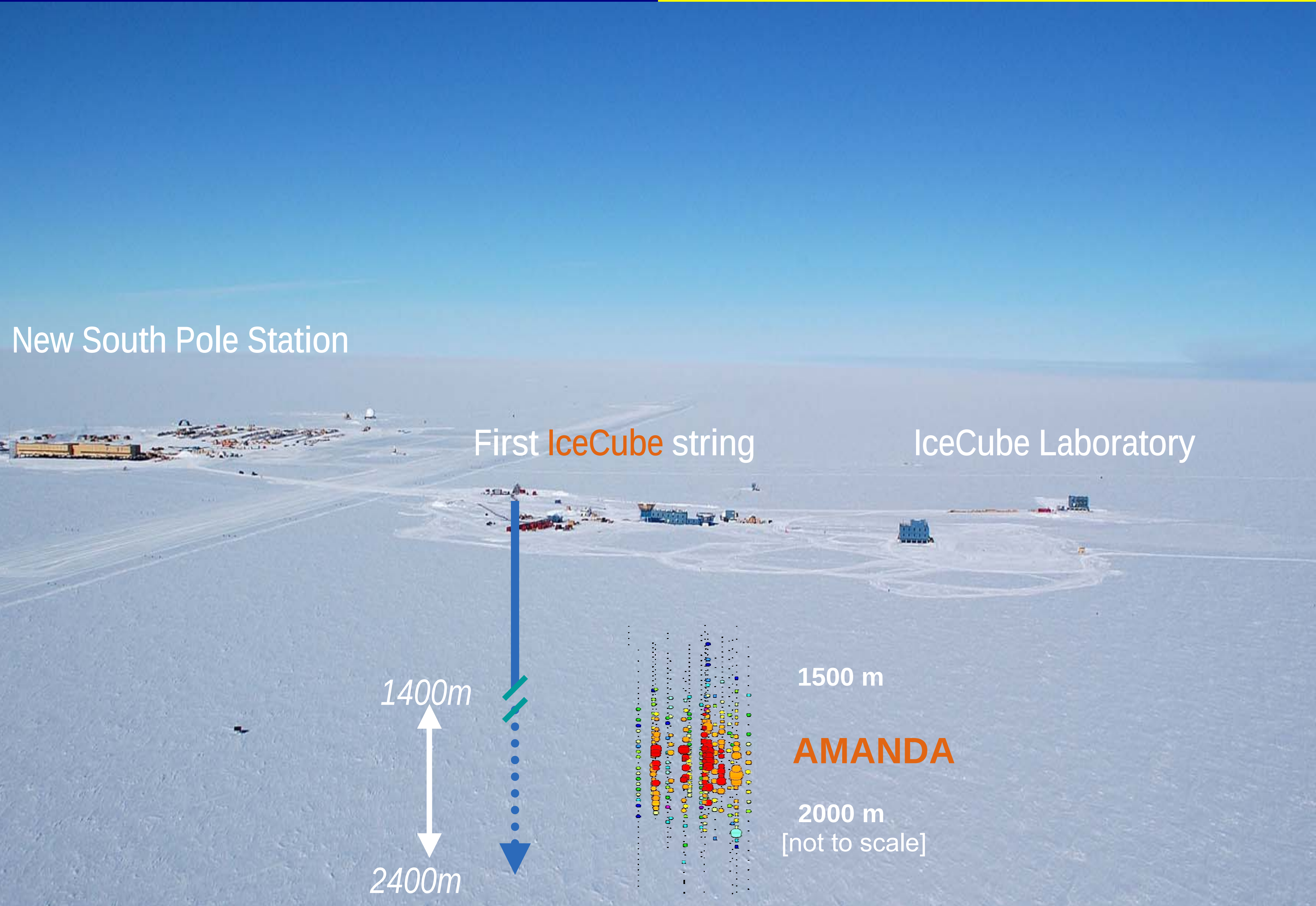
Location: South Pole	
Commissioned:	2000
(AMANDA B10 since 1997)	
No. of Strings:	19
Optical Sensors:	677
Depth:	1550-2000m
Instrum. Volume/km3:	0.016
μ-Effective area (1 TeV):	>20000 m^2
Angular resolution	1.6 - 2.5°

Deployment from ice surface.

Architecture: individual power lines (copper) and analog signal/calibration fibers to each sensor.



Neutrino Telescopes AMANDA-II



Neutrino Telescopes ANTARES

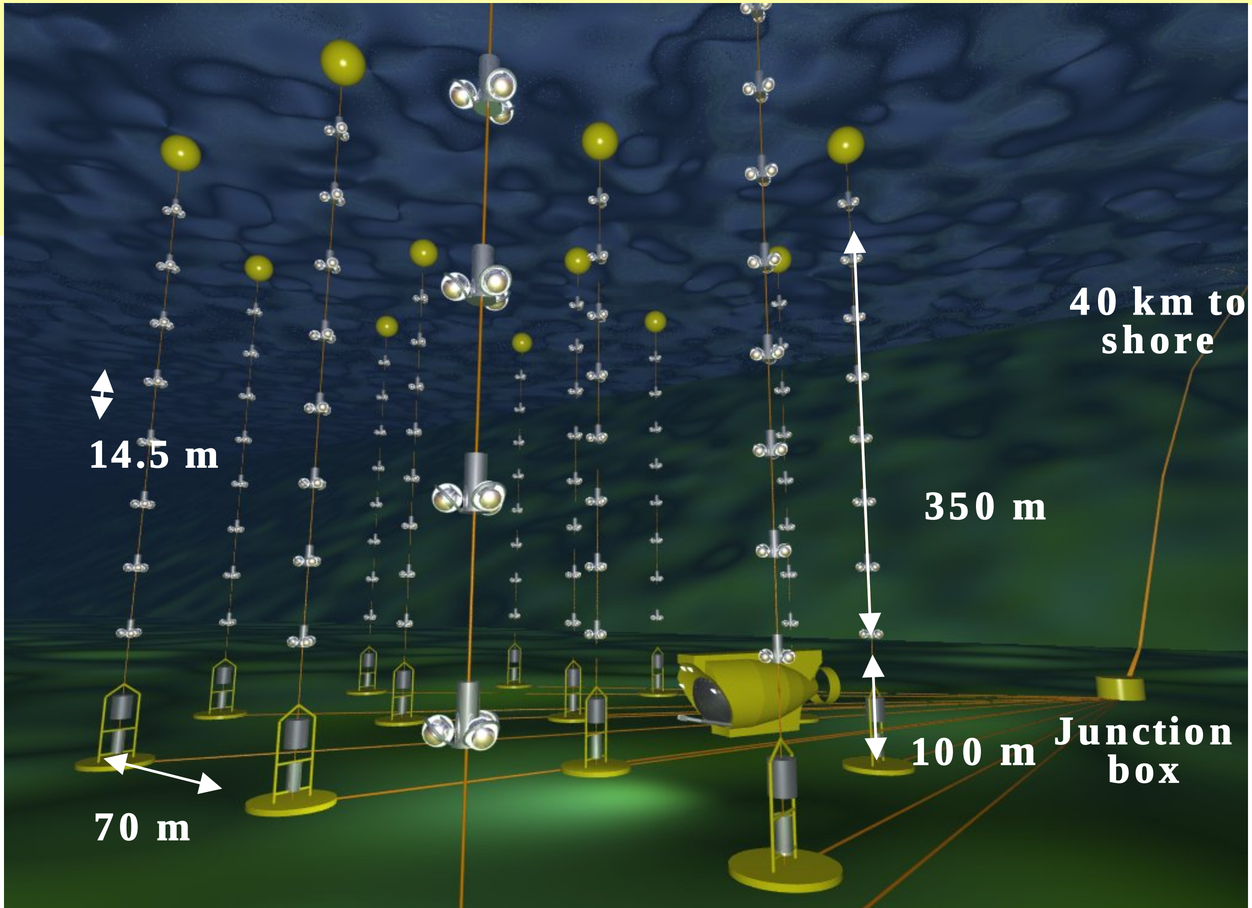
Location: Mediterranean Sea, 40 km off shore

Construction schedule:	2005 - 2007
No. of Strings:	12
Optical Sensors:	900
Depth:	2100-2400m
Instrum. Volume/km3:	0.011

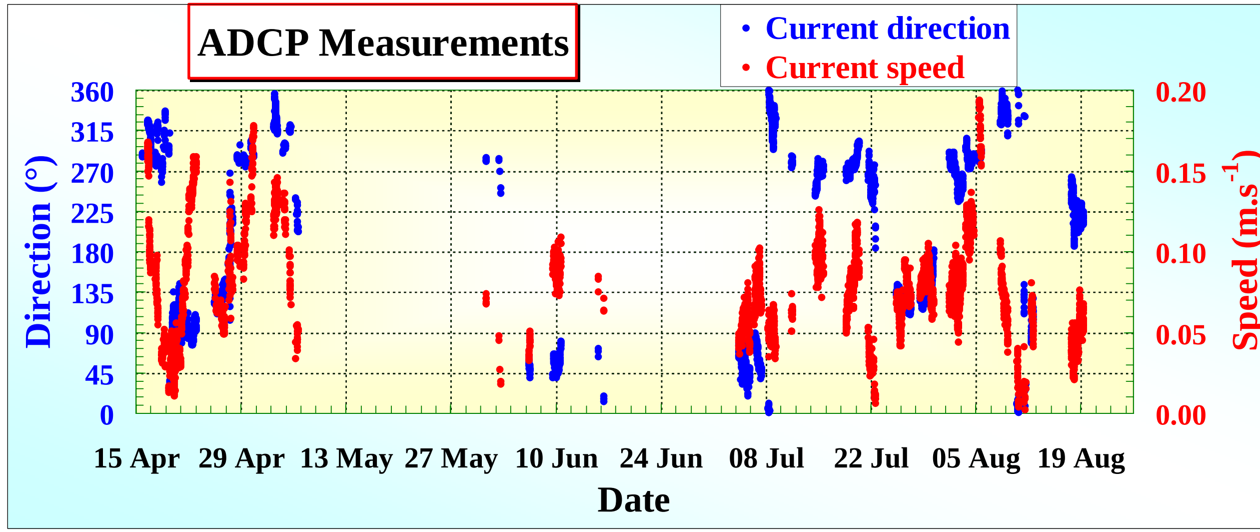
μ-Effective area (1 TeV): 0.016 km^2

Angular resolution (>10 TeV): <0.3°

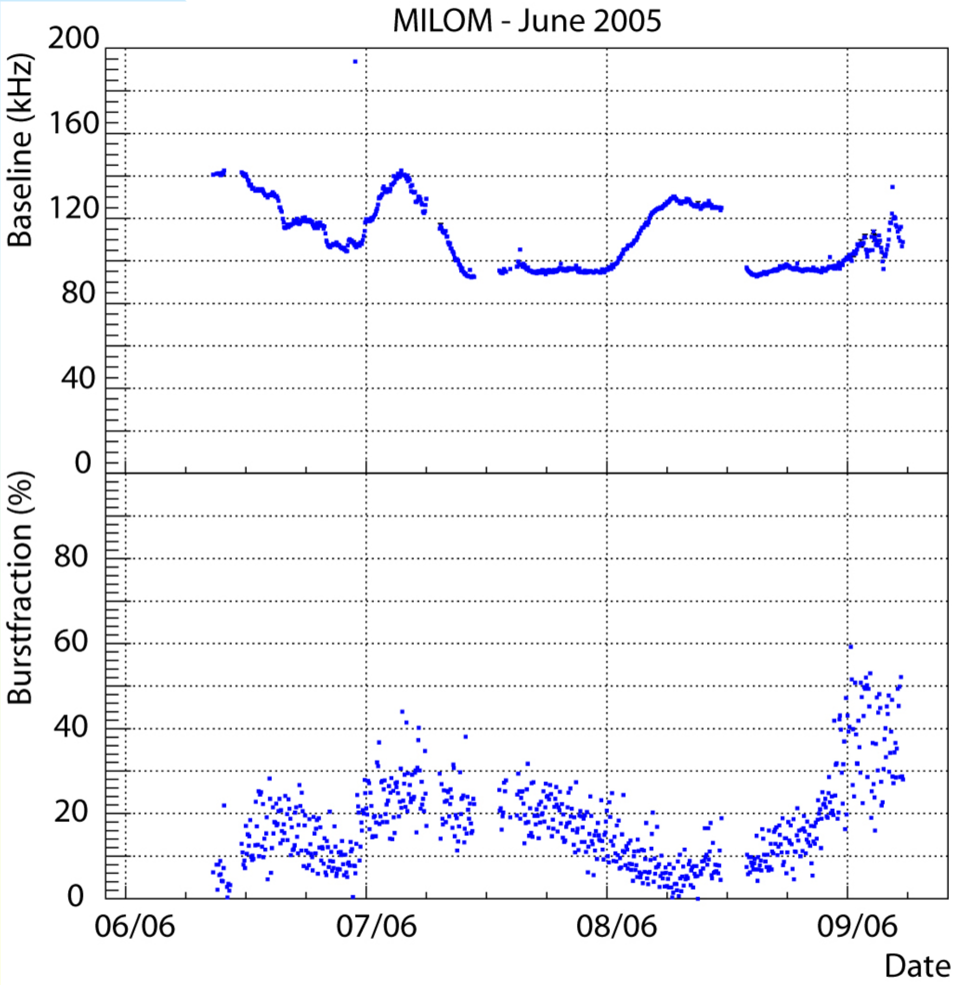
Architecture: local digitization, transmission of all data to shore.



Measurement of the water current profile using the Doppler effect



Baseline and Burst Fraction

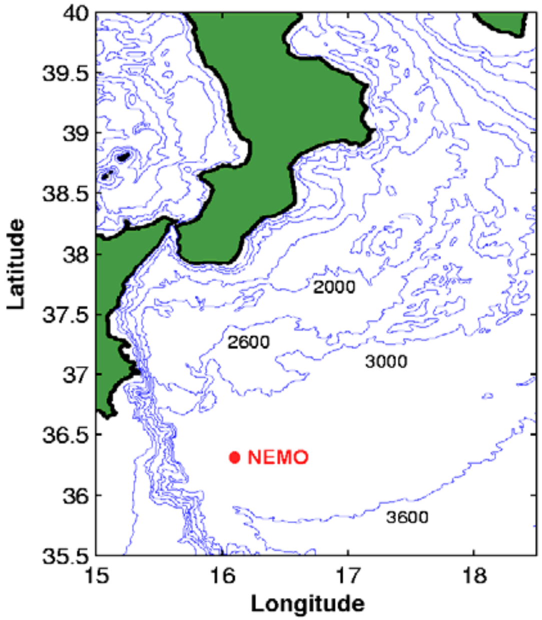


Neutrino Telescopes NEMO

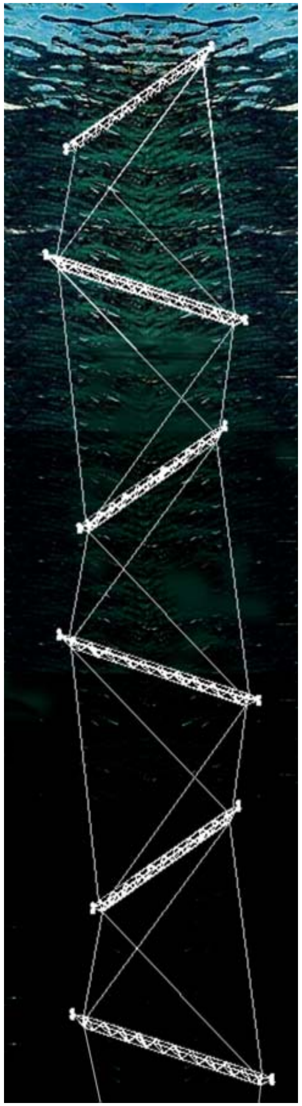
NEMO in R & D, Phase 1 (to 2006)
Location: (≈80 km) off the coast of Sicily (Capo Passero)
Optical Sensors: 5600
Depth: ≈2800 m - 3400 m
Instrum. Volume/km3: 1

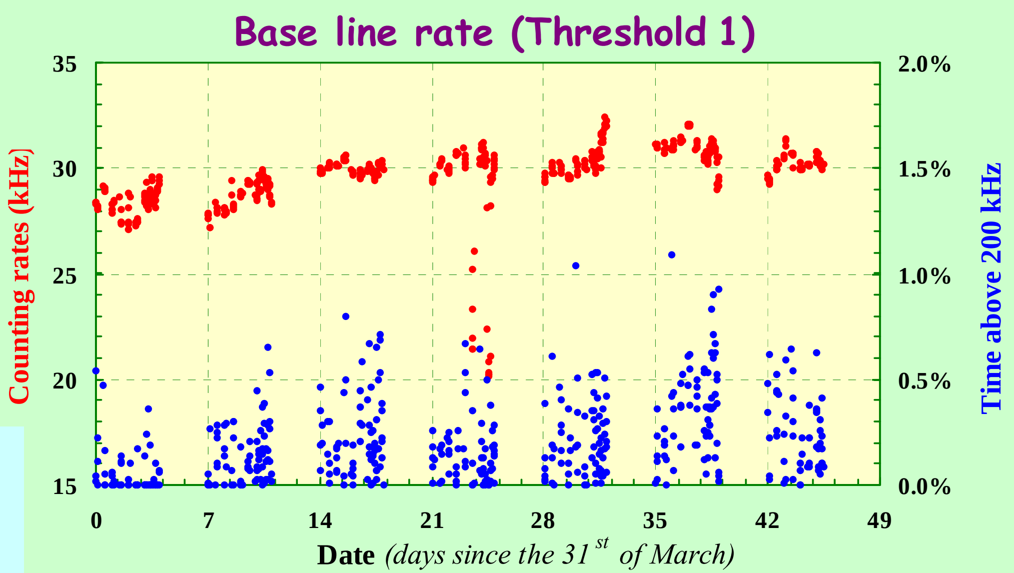
Detailed measurements and studies of water and other site parameters.

Medium is found excellent.



Tower structure





Baseline rate ~ 30 kHz

Burst fraction ~ 0.2 %

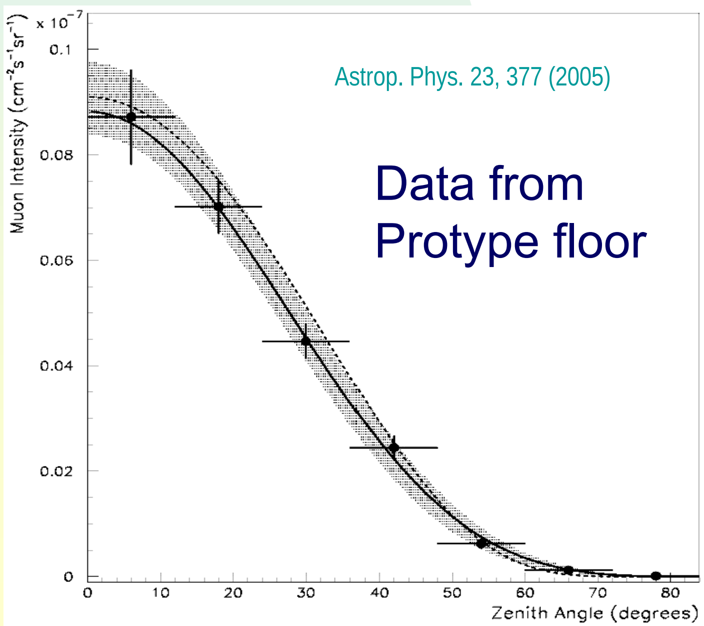
Neutrino Telescopes NESTOR

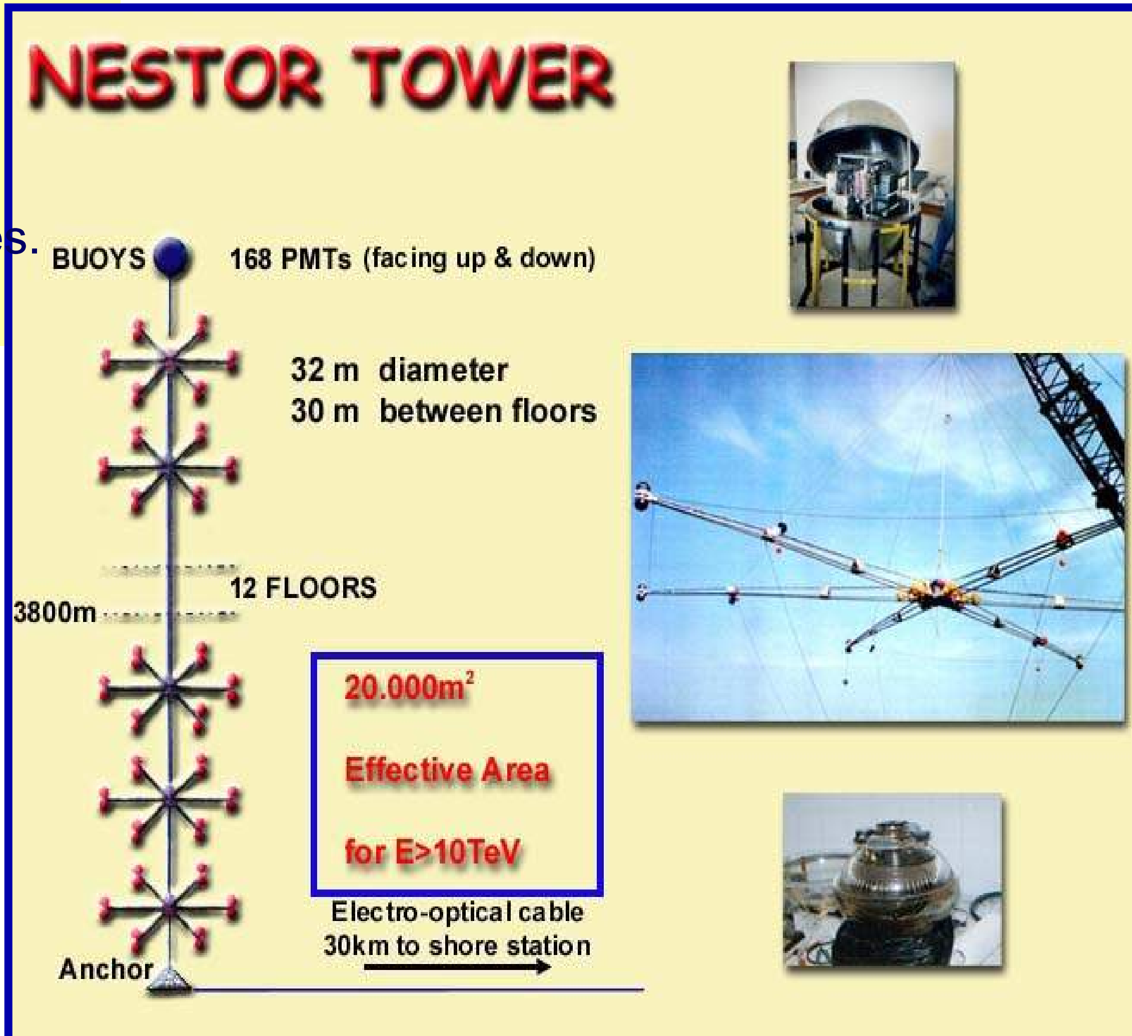
Location: Mediterranean Sea, Pylos
Construction schedule: 2005 - 2007
No. of sensors/floor: 12
Optical Sensors: 168
Pairs facing up and down

Depth (sea floor): 5200 m

Measured very good water properties.
Reconstructed events.

First floor (reduced size) with
12 PMTs deployed and operated
in 2003
Goal to deploy 4 more floors in spring 2006.





Neutrino Telescopes IceCube

Construction:	2004 - 2010

In-Ice Array:

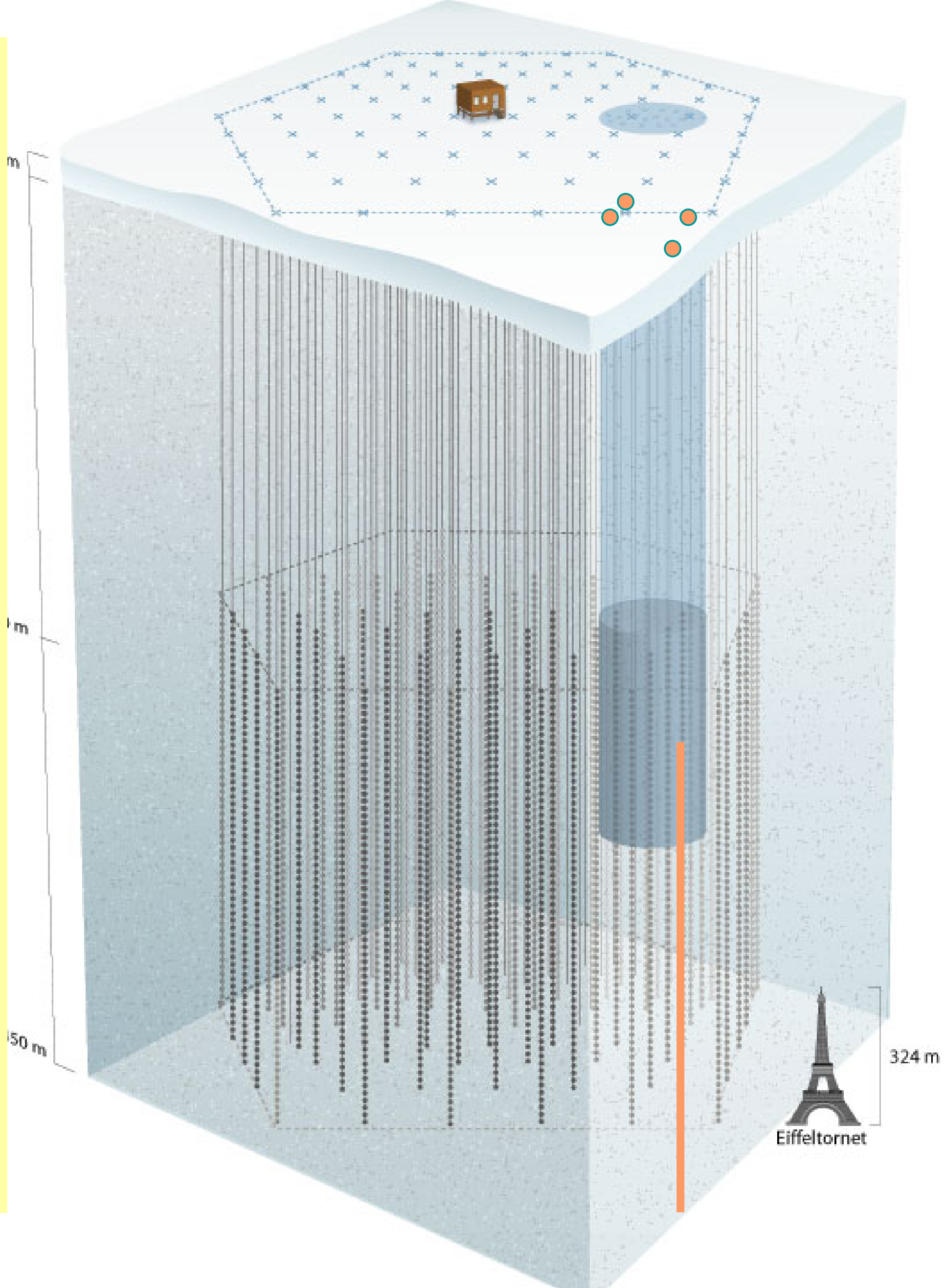
No. of Strings:	80
Optical Sensors:	4800
Depth:	1450-2450m
Instrum. Volume/km3:	0.9
μ-Effective area (1 TeV):	0.8 km^2
Angular resolution	≈0.6°

Architecture: individual power and communication lines from surface.

Surface Array - IceTop:

Surface air shower array,

160 Frozen water tanks w 2 sensors each.



Neutrino Telescopes

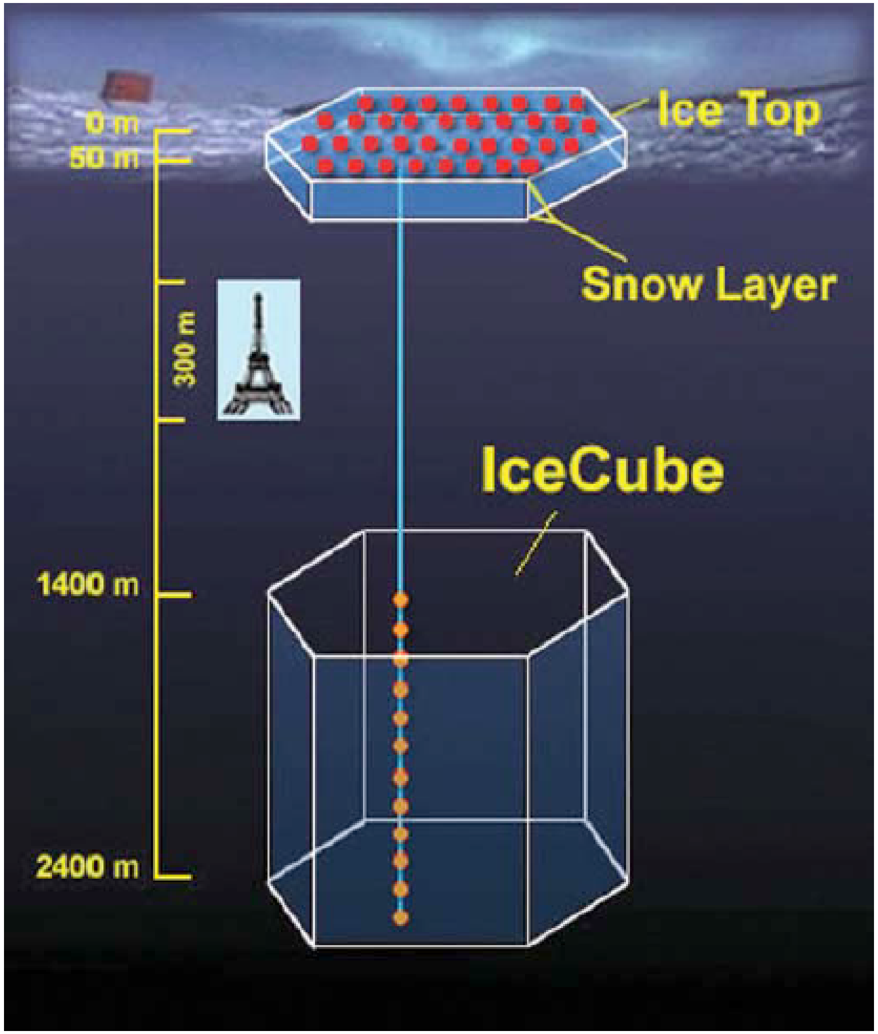
IceCube

January 2005:
1 string and 8 tanks deployed

DOM (Digital Optical Module)
Power: 3 W
Digitize at 300 Mhz (and 40 MHz)
Send all data to surface over copper
Two sensors/twisted pair.
Flasherboard with 12 LEDs
Local HV

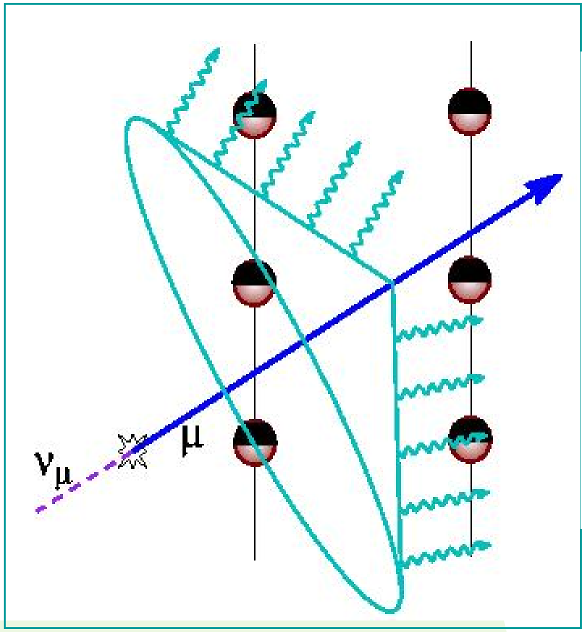
Clock stability: $10^{-10} \approx 0.1$ nsec / sec
Synchronized to GPS time every ≈ 10 sec
at a precision of rms = 2 nsec

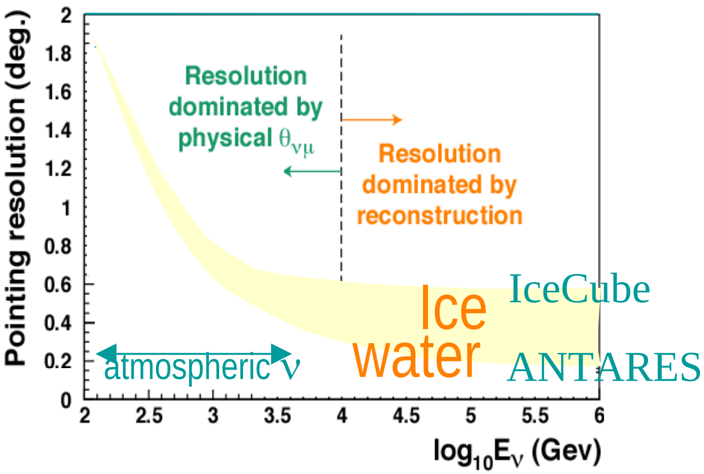
- 80 strings (60 PMT each)
- 4800 10” PMT (only downward looking)
- 125 m inter string distance
- 16 m spacing along a string
- Instrumented volume: 1 km^3 (1 Gton)
- First string to be deployed in january 2005



Neutrino Telescopes — Tracks and Cascades

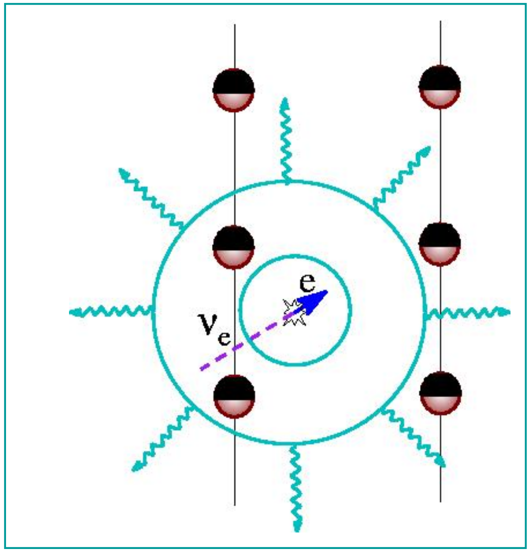
O(10 km) long muon tracks: neutrino astronomy





$$\Theta_{\mu\nu} \approx 0.7^\circ \cdot (E_\nu / \mathrm{TeV})^{-0.7}$$

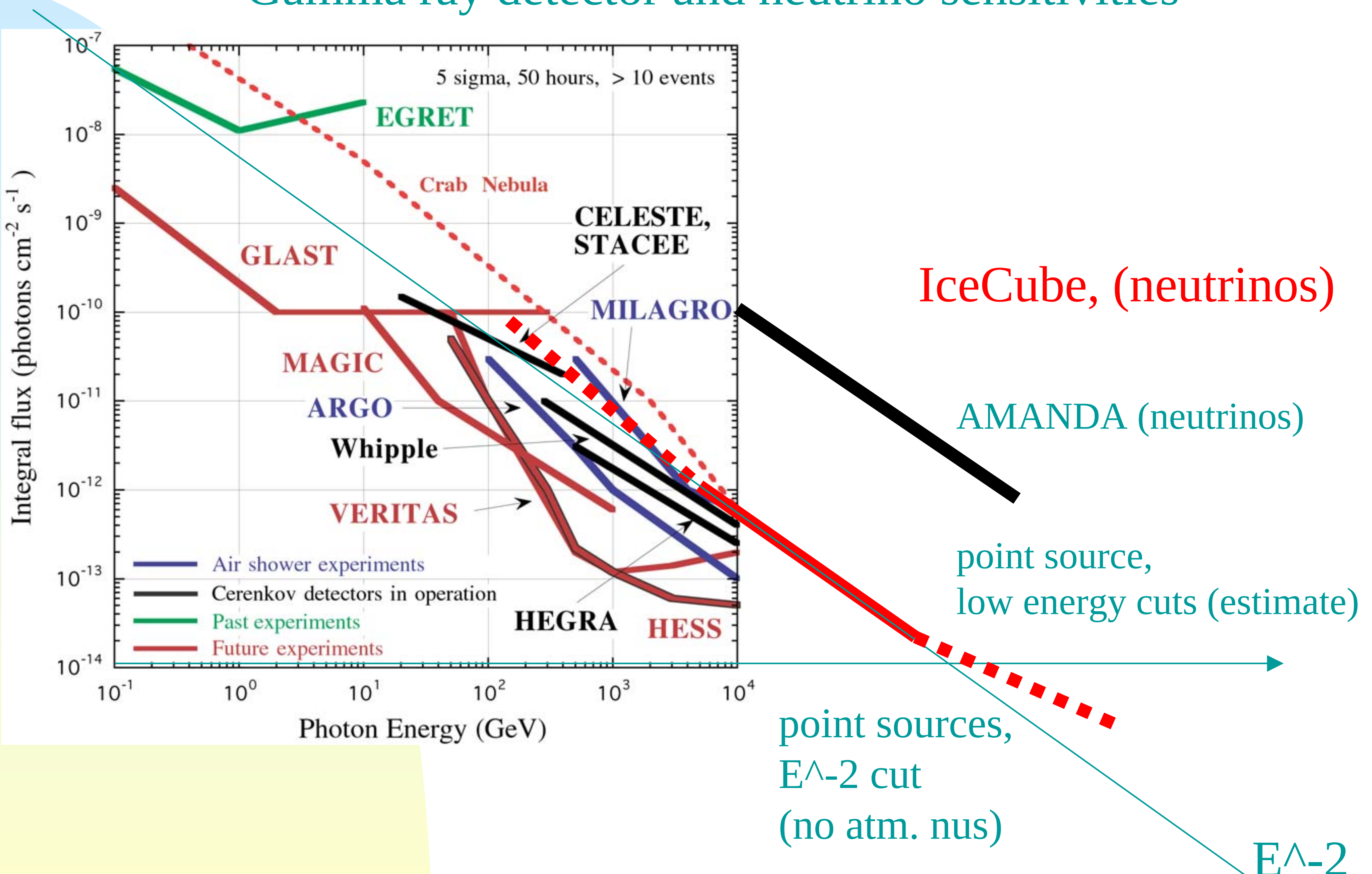
Electromagnetic and hadronic cascades: ν_e, ν_τ, neutral current.



	Muons	Cascades
Angular resolution **(background rejection, source identification, astronomy)**	Good: 0.3° to 3° Depending on energy and detector/medium	Relatively poor: Possibly 10°(ANTARES?) to 30°
Energy resolution **(background rejection, energy determination)**	Typically, ≈ 0.25 to 0.5 in Log(E_μ) (not E_ν)	Good: ≈ 0.1 to 0.2 of log(E_ν) (all energy deposited! Calibrate w. lasers.)

Outlook Perspectives

Gamma ray detector and neutrino sensitivities



Sensitivity (2π sr, 100% ontime):
3 years exposure, 5 sigma