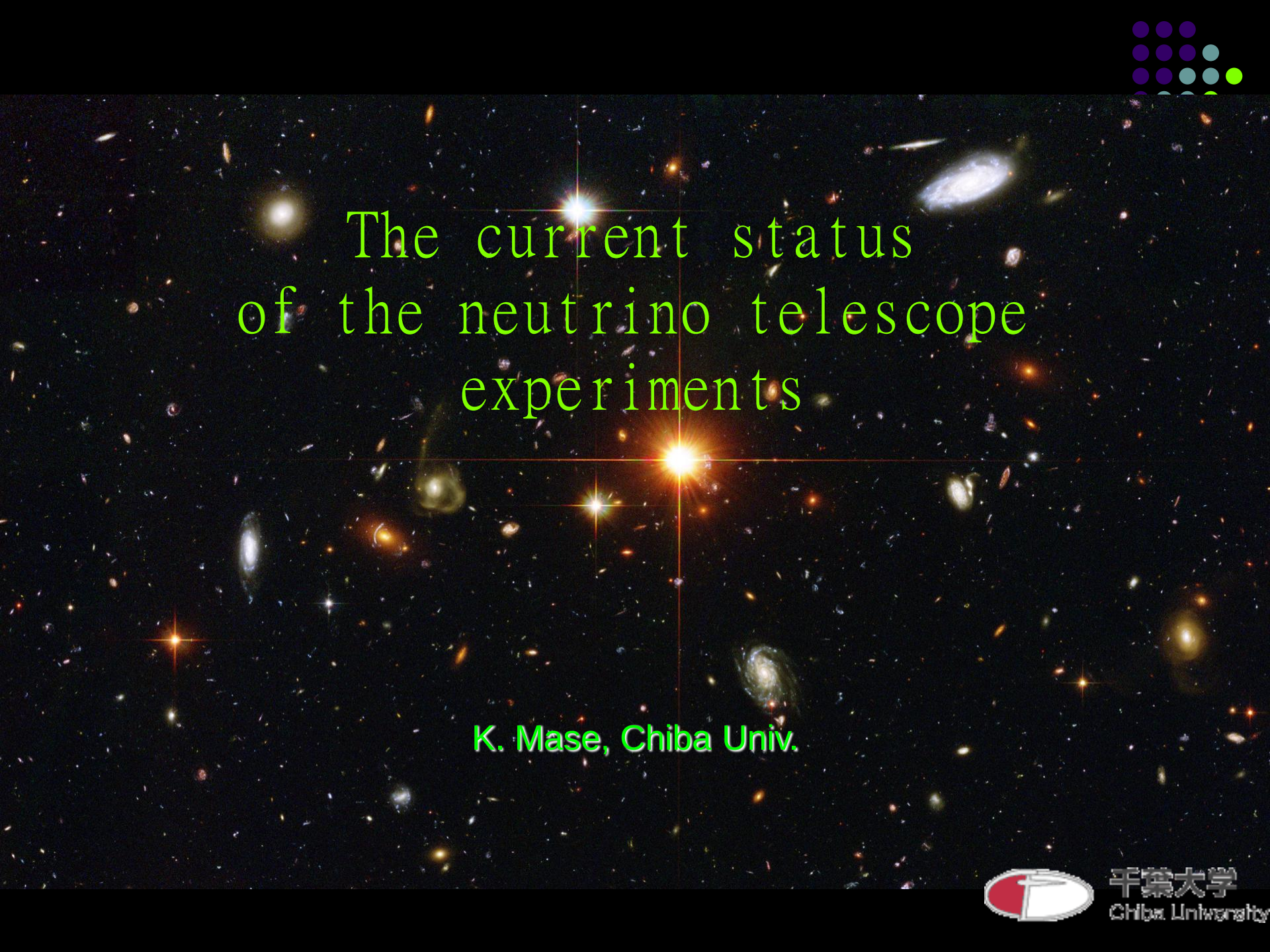
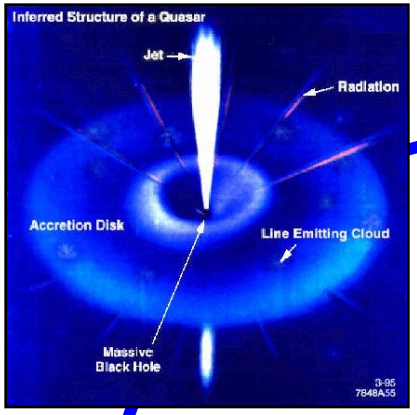
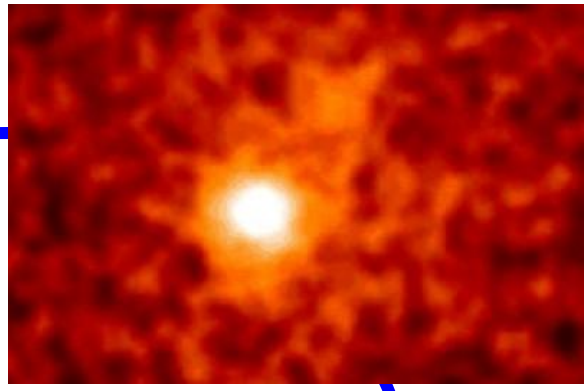

The current status
of the neutrino telescope
experiments
K. Mase, Chiba Univ.
千葉大学
Chiba University

The neutrino astronomy

Want to open the neutrino astronomy



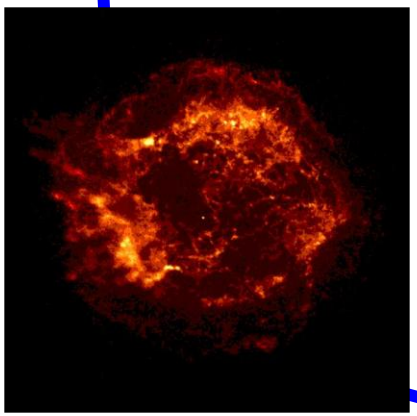
- AGNs



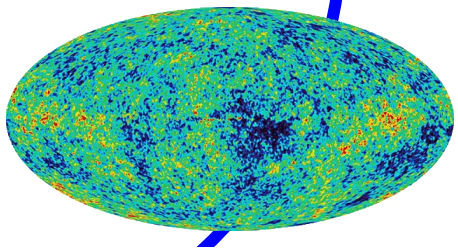
- GRBs

- Dark Matter
- **particle physics**

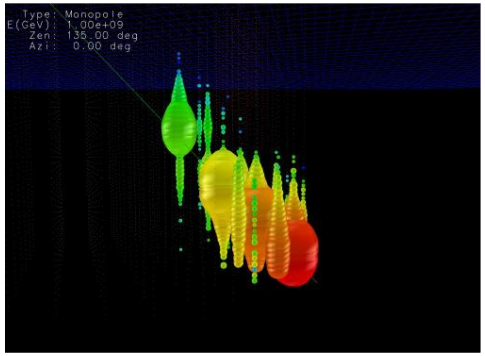
- **Cosmic ray origin**



- Supernova



- GZK neutrinos



- Exiotic
(monopole, Q-ball, etc…)

Neutrinos should be there…

The source of cosmic rays will be the neutrino source.

$$p\gamma \rightarrow n\pi^{+} \rightarrow \mu\nu_{\mu}$$

Waxman-Bahcall limit

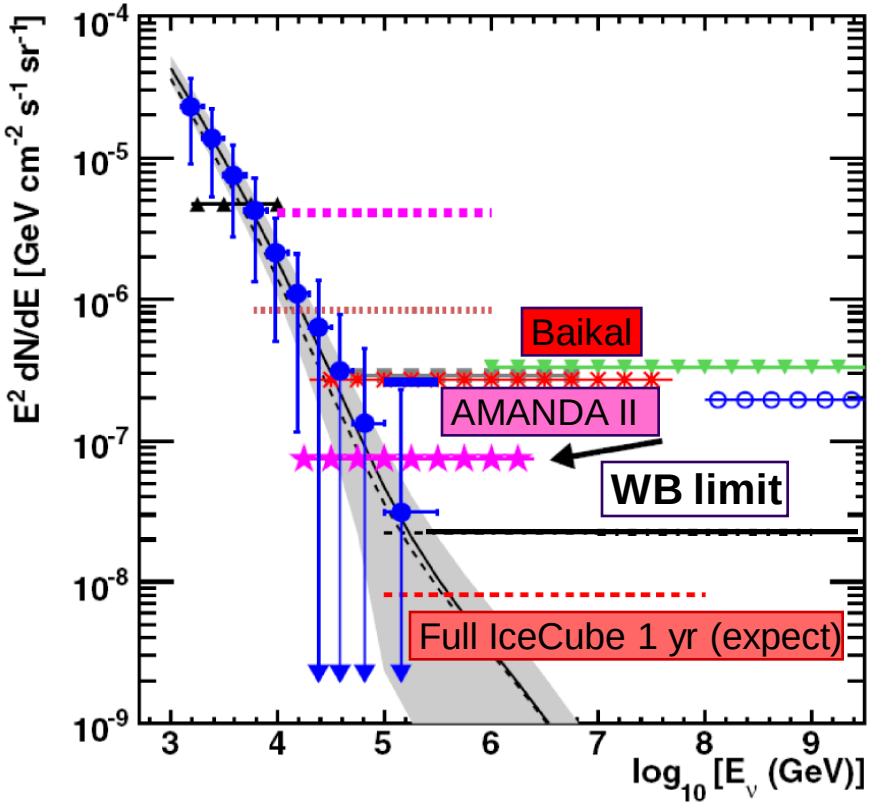
$$E_{\nu}^{2}\Phi_{\nu_{\mu}} = \frac{\varepsilon}{8}\xi_{Z}t_{H}\frac{c}{4\pi}E_{CR}^{2}\frac{d\dot{N}_{CR}}{dE_{CR}}$$

ε: fraction of energy going to neutrinos

If ε=1, WB limit

$$E_{\nu}^{2}\Phi_{\nu_{\mu}} \approx 2\times10^{-8}\ GeV\ cm^{-2}s^{-1}sr^{-1}$$

The sensitivity of 1 km^3 size detector is lower than WB limit.



But, where?

Where are cosmic rays generated?

→ we don't know yet

(We know where electrons are accelerated)

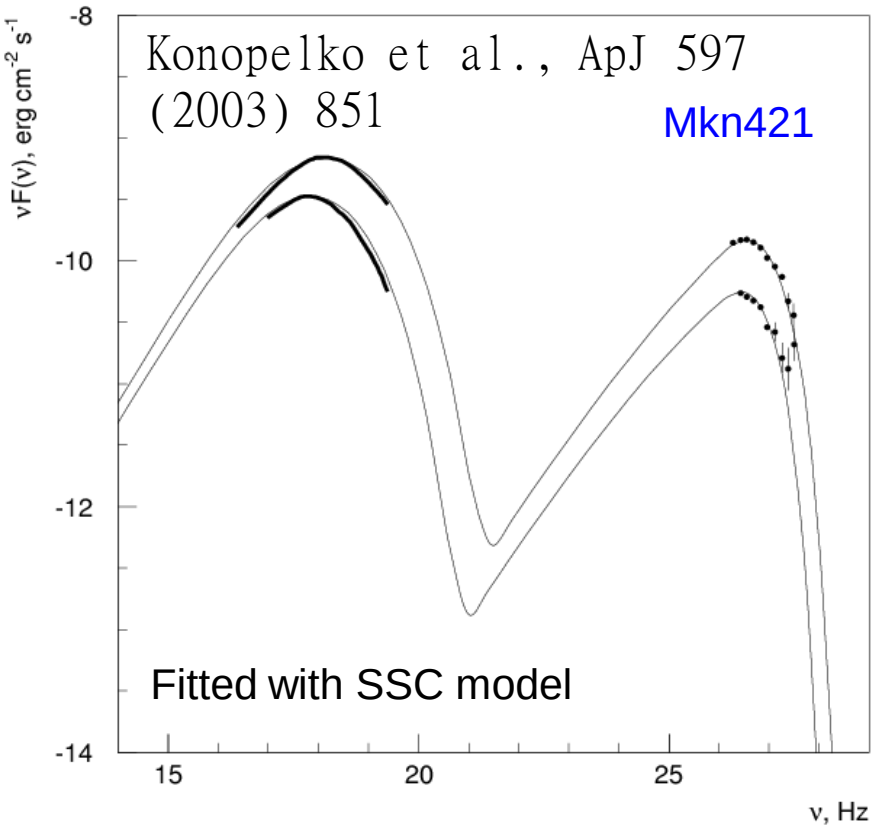
→ Neutrinos can tag it.

Note: if there is a photo-pion production, roughly same amount neutrinos and gammas are generated.

Even more if we consider gamma-ray absorption.

The flux (>1TeV) can be $10^{-11}(cm^{-2}s^{-1})$ and detectable with 1 km^3 detector.

(A. Aharonian et al., MNRAS 387,3, 1206-1214, 2008)

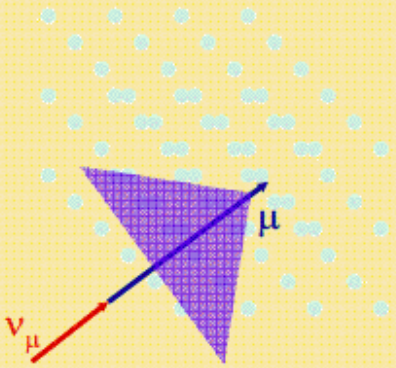


The detection method

Large Area Detectors for HE neutrinos

1 TeV — 100 PeV — 1000 ZeV

Optical Detection (ICECUBE-KM3NeT)



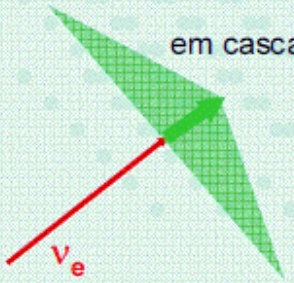
Medium: Seawater, Polar Ice

ν_μ (throughgoing and contained)
$\nu_{e,\tau}$ (contained cascades)

Carrier: Cherenkov Light (UV-visible)
Attenuation length: 100 m

Sensor: PMTs
Instrumented Volume: 1 km^3

Radio Detection (RICE, SALSA)



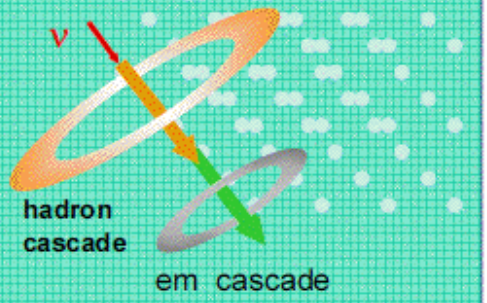
Medium: Salt domes, Polar Ice

ν (cascades)

Carrier: Cherenkov Radio
Attenuation length: 1 km

Sensors: Antennas
Instrumented Volume: >1 km^3

Acoustic Detection (Prototypes)



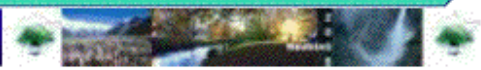
Medium: Seawater, Polar Ice, Salt Domes

ν (cascades)

Carrier: Sound waves (tens kHz)
Attenuation length: ~ 10 km

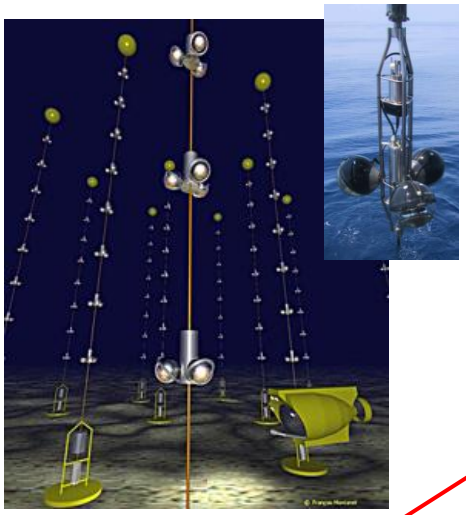
Hydro(glacio)-phones
Instrumented Volume: >100 km^3

Giorgio Riccobene — INFN LNS

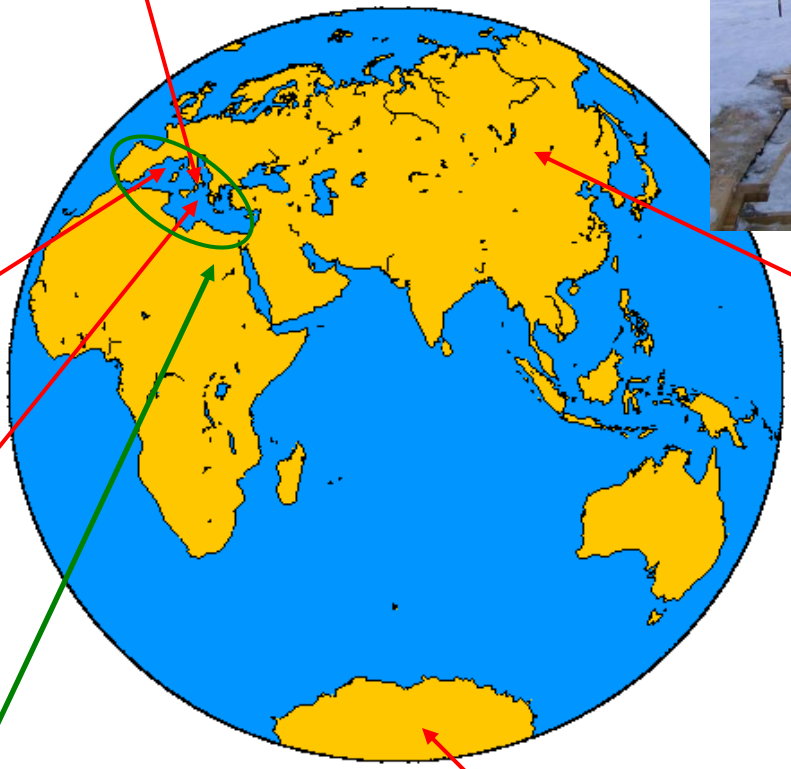


…Dumand

Optical Neutrino Telescopes



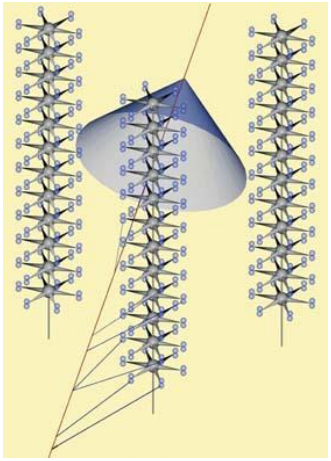
Nemo



Lake Baikal

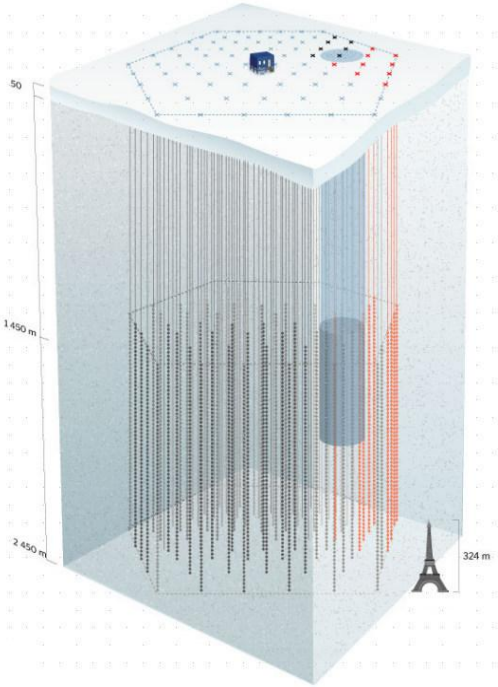
Antares

Nestor



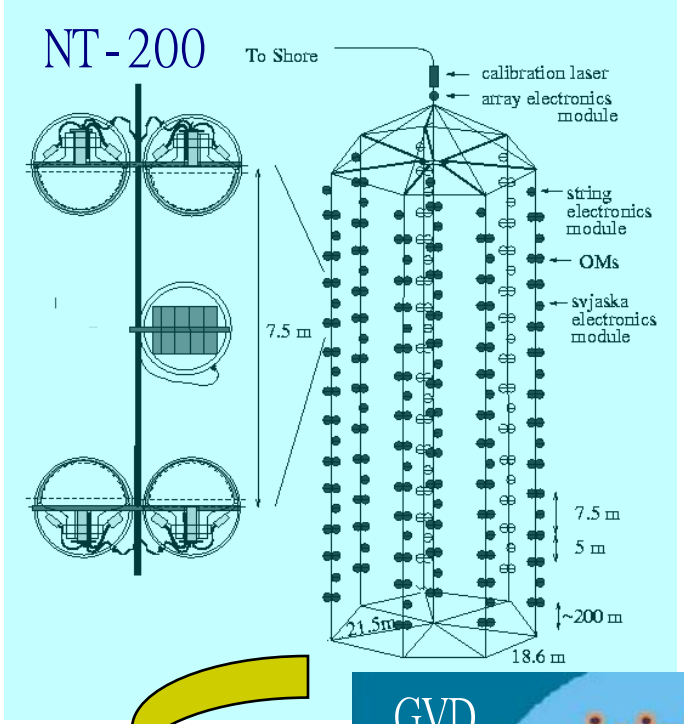
KM3Net

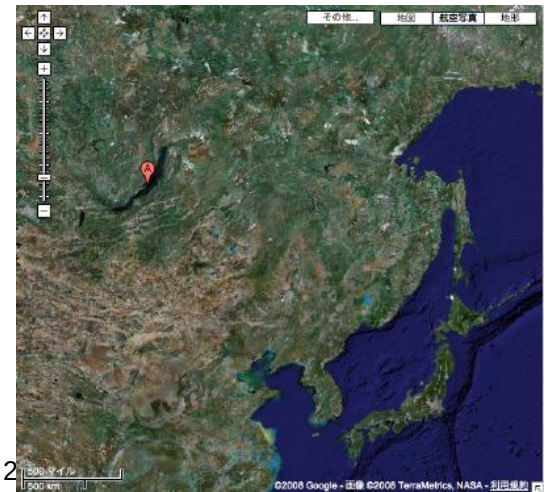
AMANDA /
IceCube

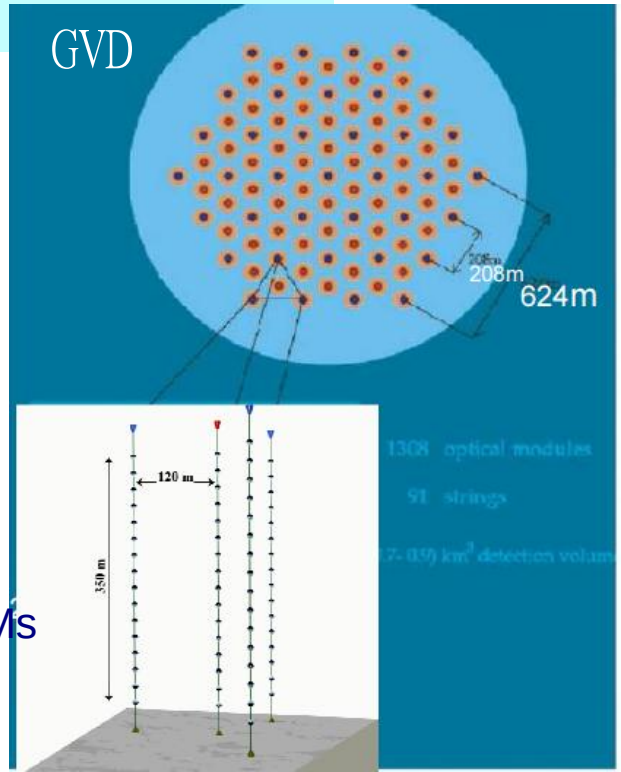


Baikal

- deployed in lake Baikal
- Long history
- 1.4 km depth
- 1980: R&D started
- 1993: NT-36 (36 PMTs with 3 strings)
- 1998: NT-200 completed (192 OMs (14.6" PMT), 8 strings ~10^5 m^3)
- 2005: NT-200+ (NT-200 + 3 outer strings) completed
- 2006/7: R&D of Gigaton Volume Detector(GVD)
- 2008: a prototype of GVD installed (testing new PMTs and 250M SPS FADC)





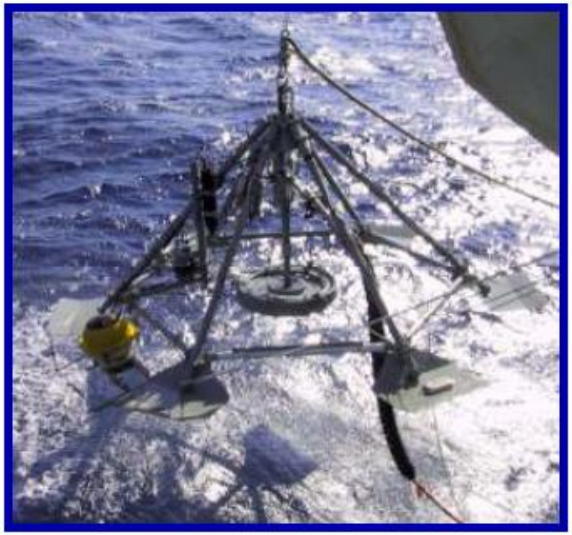


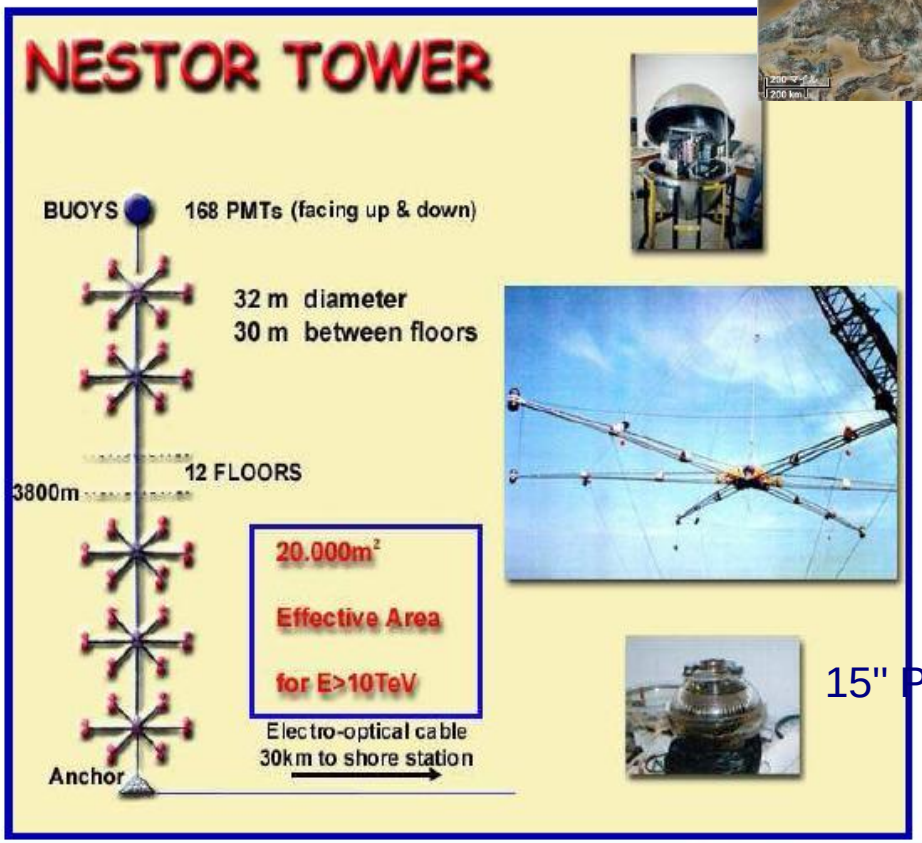
91-100 strings with 12-16 OMs

Δlog(E)~0.1, Δθ<5 deg.

NESTOR (Neutrino Extended Submarine Telescope with Oceanographic Research)

- Tower based detector
- Up- and downward looking PMTs
- 4000 m deep
- Dry connections
- Test floor (reduced size, 12 m) with 12 PMTs deployed and operated in 2003





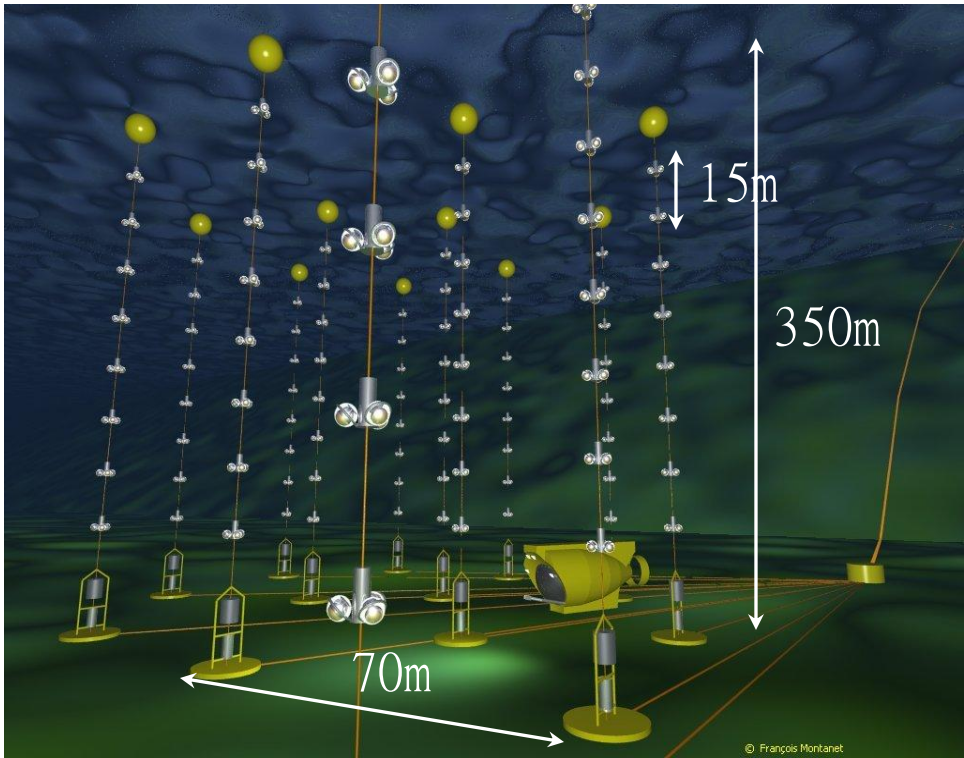
15" PMT

E. Migneco Neutrino 2008

→ Going to KM3NeT and NuBE NESTOR (GRB search)

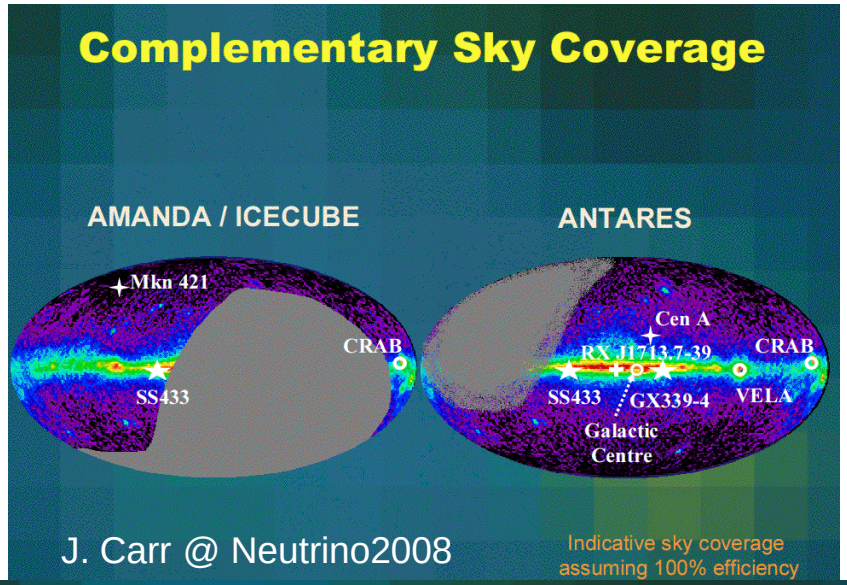
ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch)

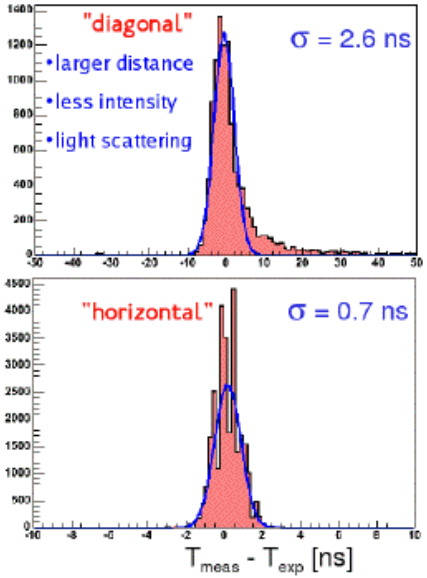
- deployed in the Mediterranean sea
- 2.5 km depth
- 1996-2000: R&D
- 2001: The deployment started
- The construction completed (2008/5/30) (12 lines ~ 10^7 m^3)
- 3x25x12=900 OMs (10" PMT)
- 300-1100 MHz ARS
- technology proven. (although 12% of the detectors had problems, but can be fixed.)
- ready for KM3NeT

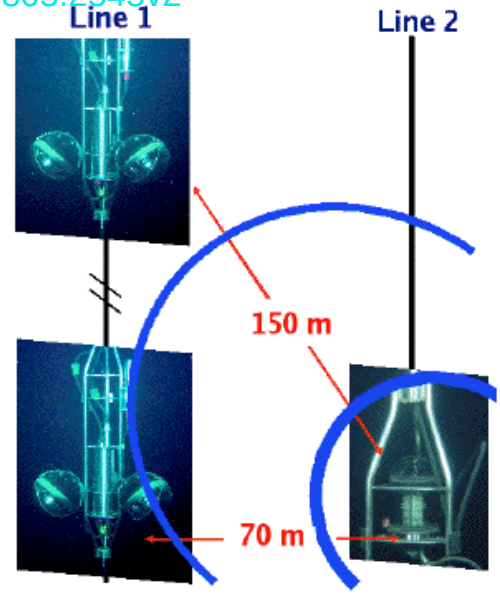


ANTARES

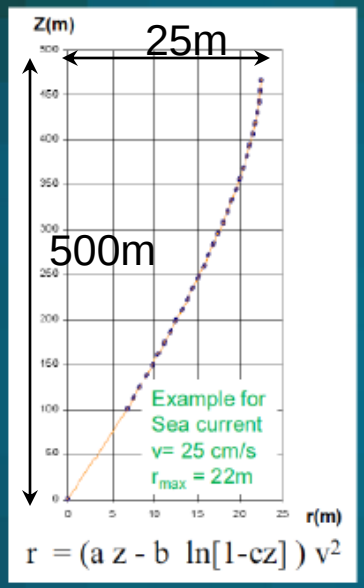
[astro-ph] 0805.2545v2

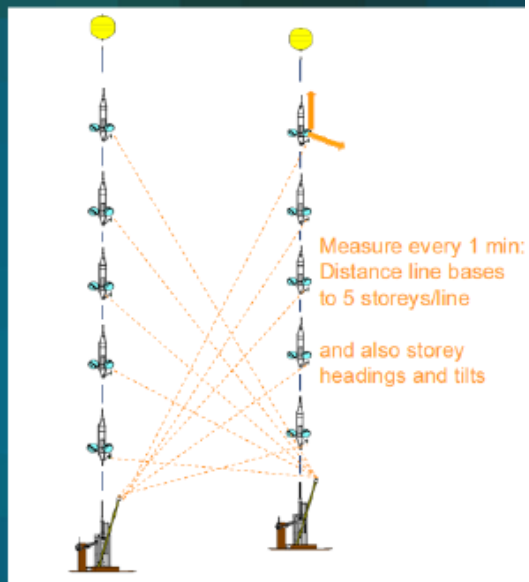


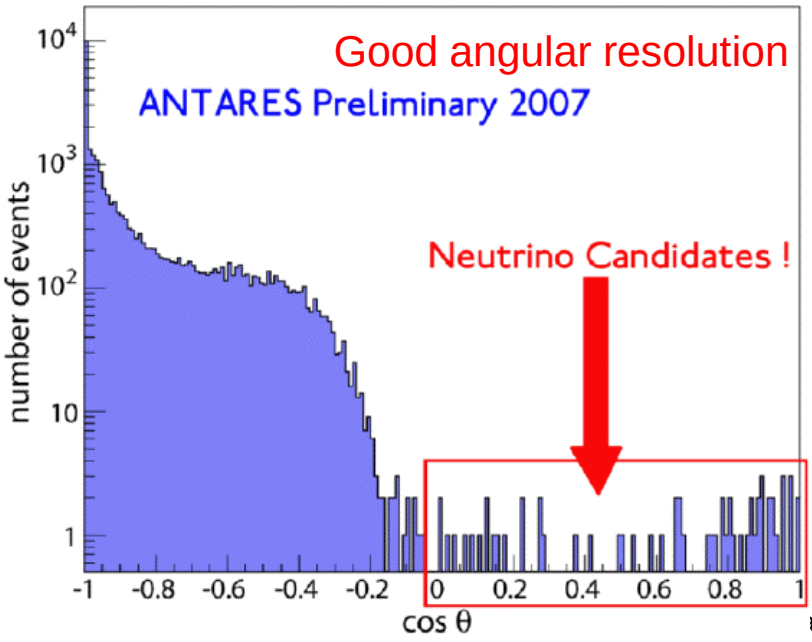




Position alignment







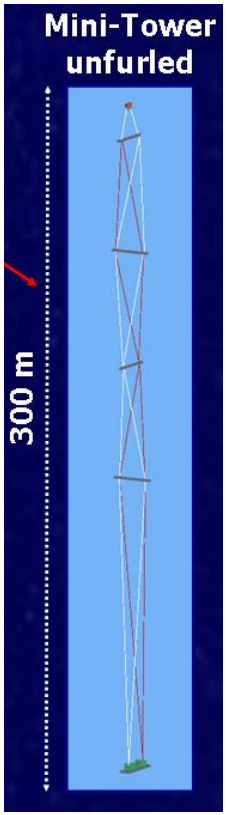
NEMO (NEutrino Mediterranean Observatory)

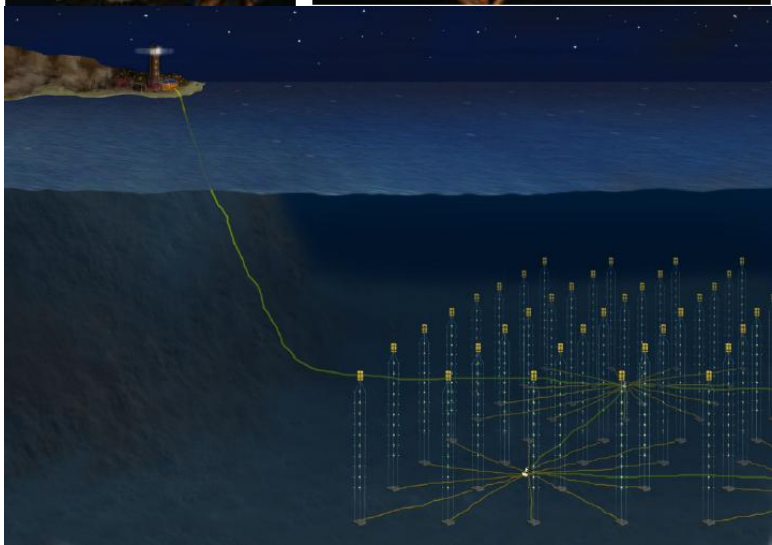
- R&D for 1 km^3 detector
- deployed in the Mediterranean sea
- phase1: 2003-2007 @ LNS test site (2 km depth)

A mini-tower (300 m) deployed Dec. 2006

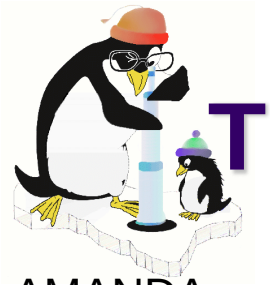
(4 floor, 16 OMs, 10" PMT)

- Some problems with the buoy



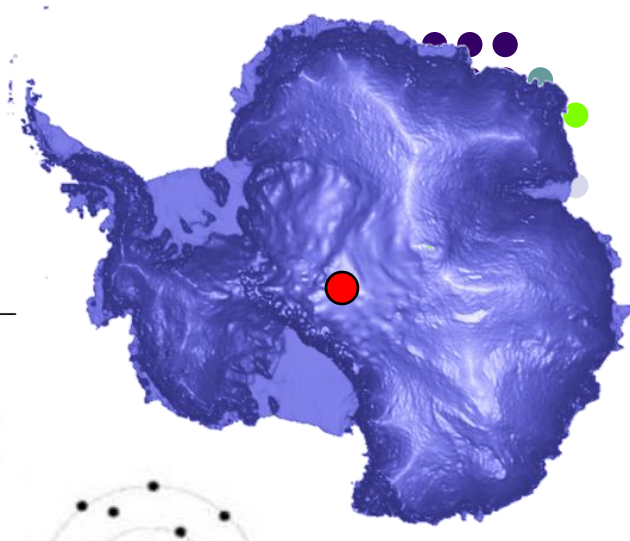


- phase2: 2006-2009 @ Capo Passero site (3.5 km depth)
- A full tower (750 m, 16 floor)
- under construction (plan to be completed at beginning of 2009)



AMANDA

The AMANDA Detector



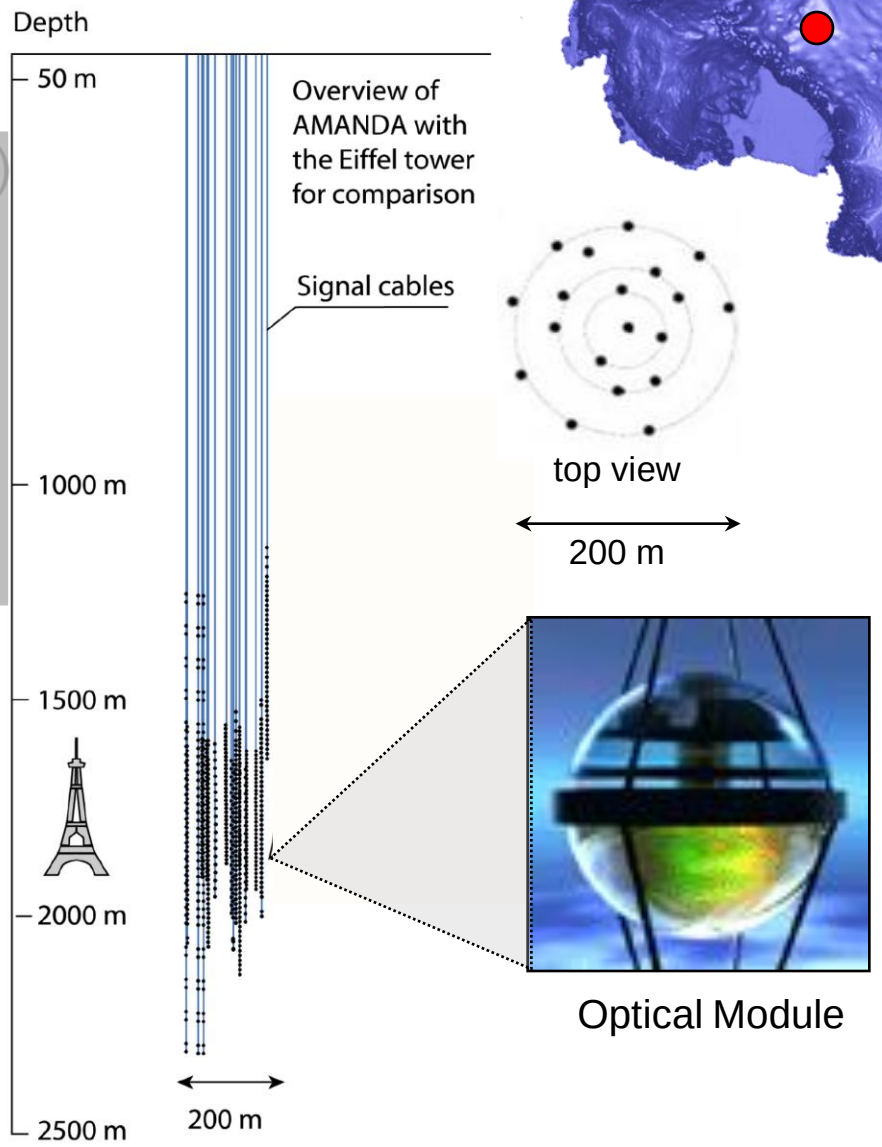
677 OMs on 19 strings (~$10^7 m^3$)

Hamamatsu 8” PMT in glass pressure vessel

Several readout systems (electrical, fiber-optic)

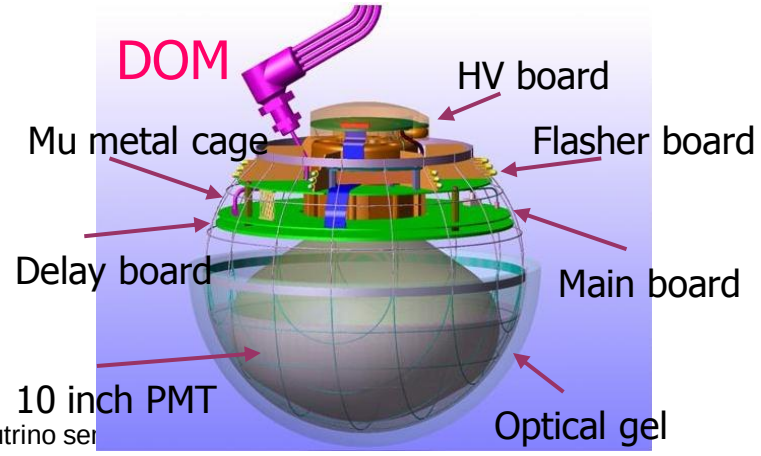
DAQ electronics on surface

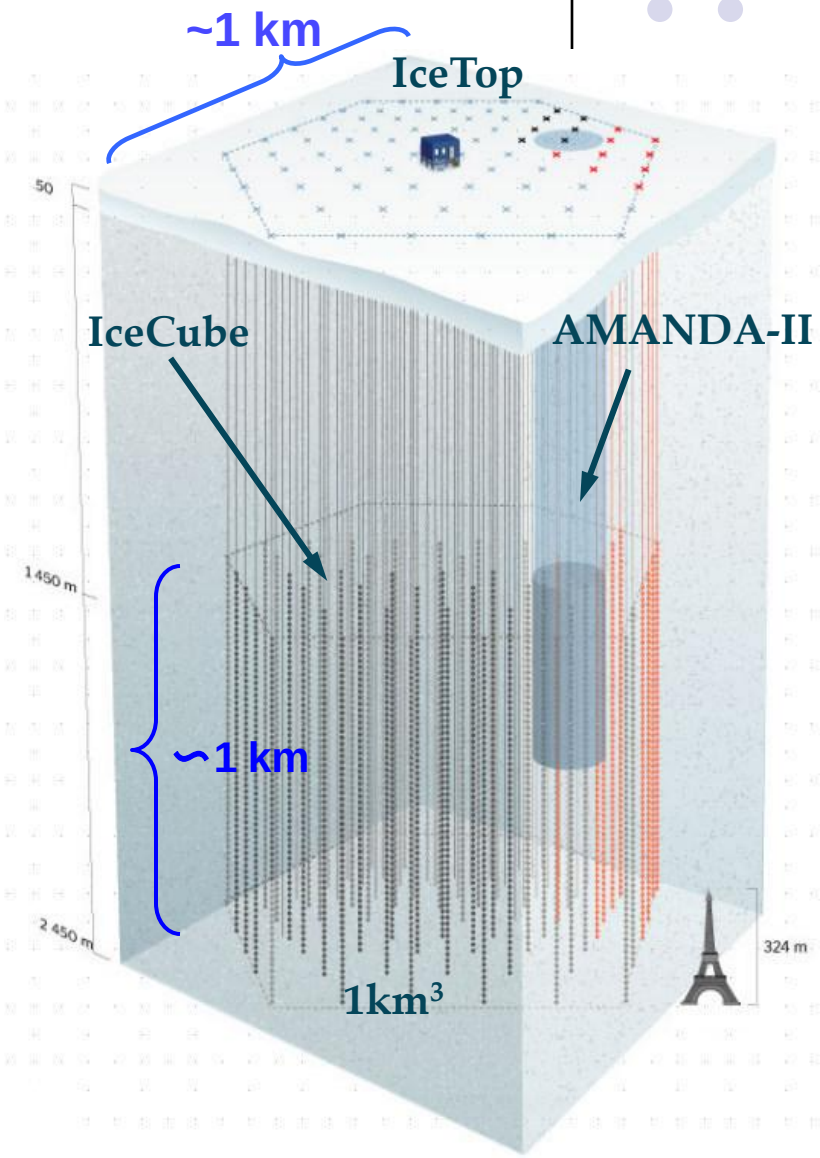
Deployed in stages:
AMANDA-II complete in 2000



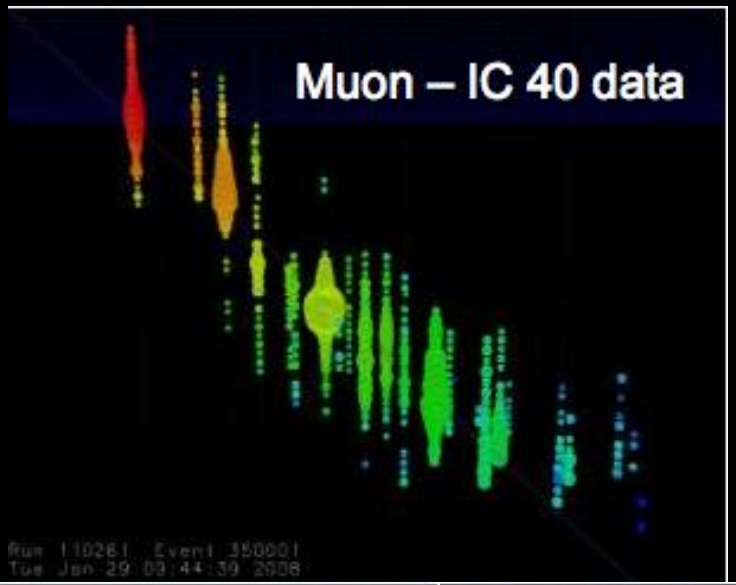
The IceCube experiment

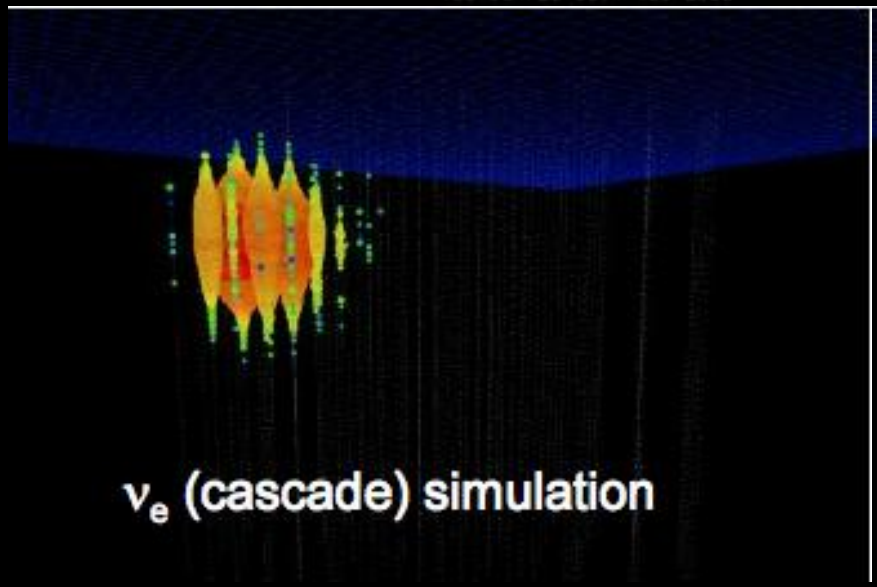
- to detect VHE neutrinos from astrophysical sources
- deployed in the Antarctica glacier
- >70 strings
- >4200 photo-multiplier tubes (PMTs)
- Detector volume: ∽1km^3
- ATWD 300MHz, effectively 16 bits
- 3 different gains (x16, x2, x0.25)
- 10 bits FADC for long duration pulse
- Neutrino energy of above 100 GeV is detectable.
- 40 strings are deployed so far, and taking data as the biggest neutrino detector.
- full detector @2009/10

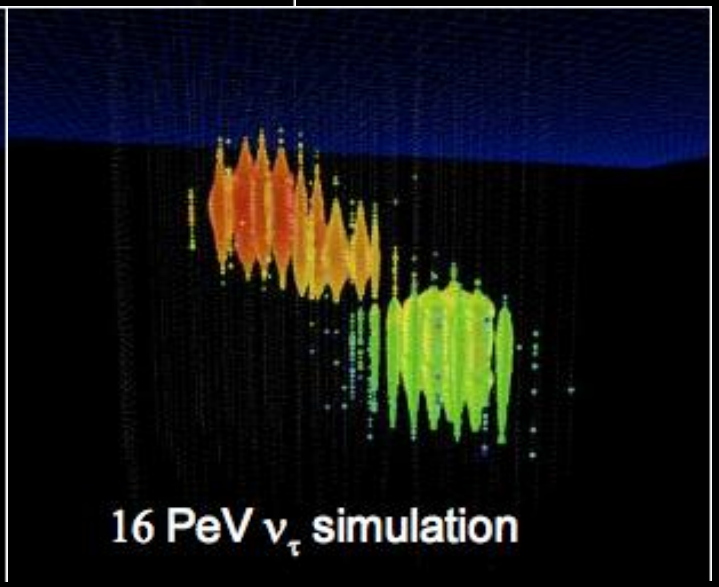




Particle identification



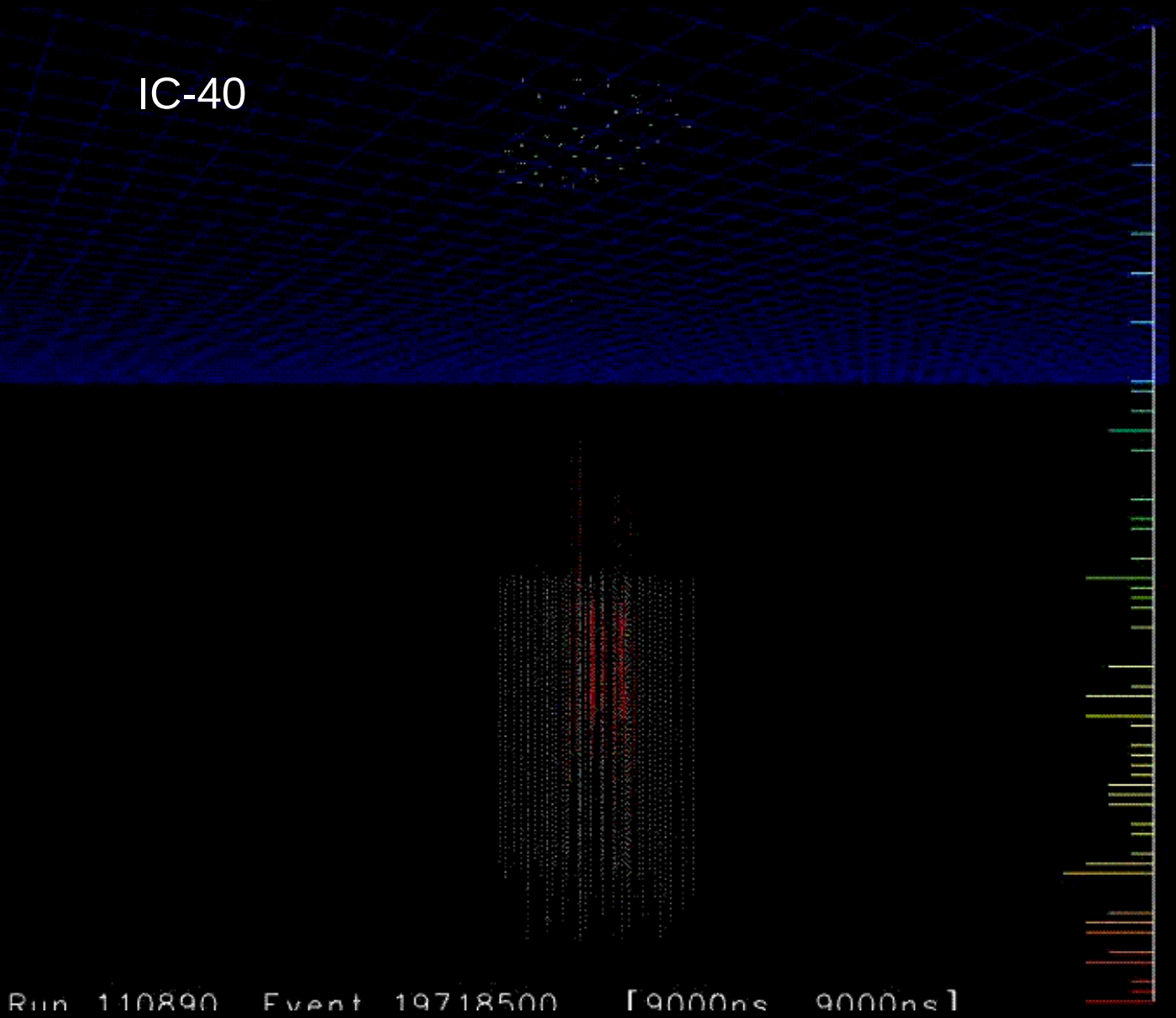




Particle identification possible from the topology

Bright event

IC-40



Estimated energy: 866 PeV

(by IceTop (preliminary))

In-ice detector also give the consistent energy

KM3NeT

European community is proposing to build 1 km^3 volume detector in Mediterranean sea.

Mostly from ANTARES, NESTOR and NEMO.

- Design Study (2006-2009):

aims at developing a cost-effective design for the construction of a 1 km^3 neutrino telescope

- Preparatory Phase (2008-2010):

preparing for the construction by defining the legal, financial ad governance issues as well as the production plans of the telescope components

(from E.Migneco@Neutrino2008)

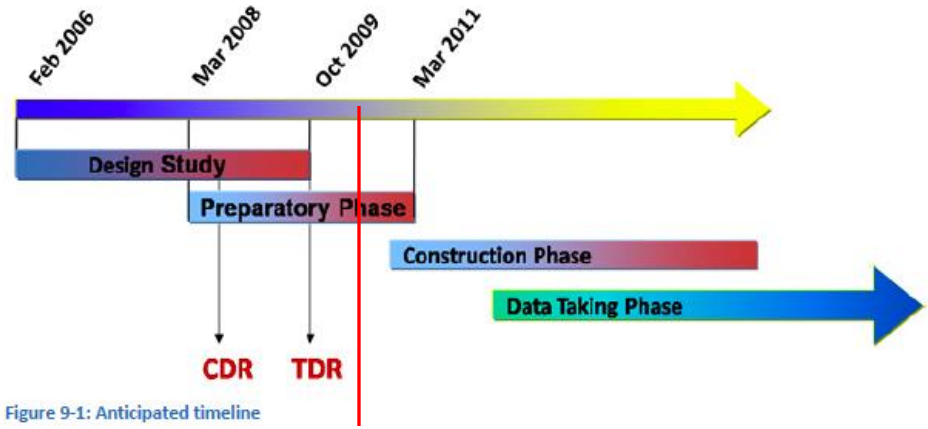


Figure 9-1: Anticipated timeline

2010: IceCube complete

Design goal

- Life time 10 years without major maintenance, construction and deployment < 4 years
- Angular resolution 0.1 deg
- Substantially better sensitivity than IceCube

(from E. Migneco@Neutrino2008)

See more the KM3NeT conceptual design report

→ http://www.km3net.org/CDR/CDR-KM3NeT.pdf

Point source search by AMANDA II

Unfortunately, no signal so far…

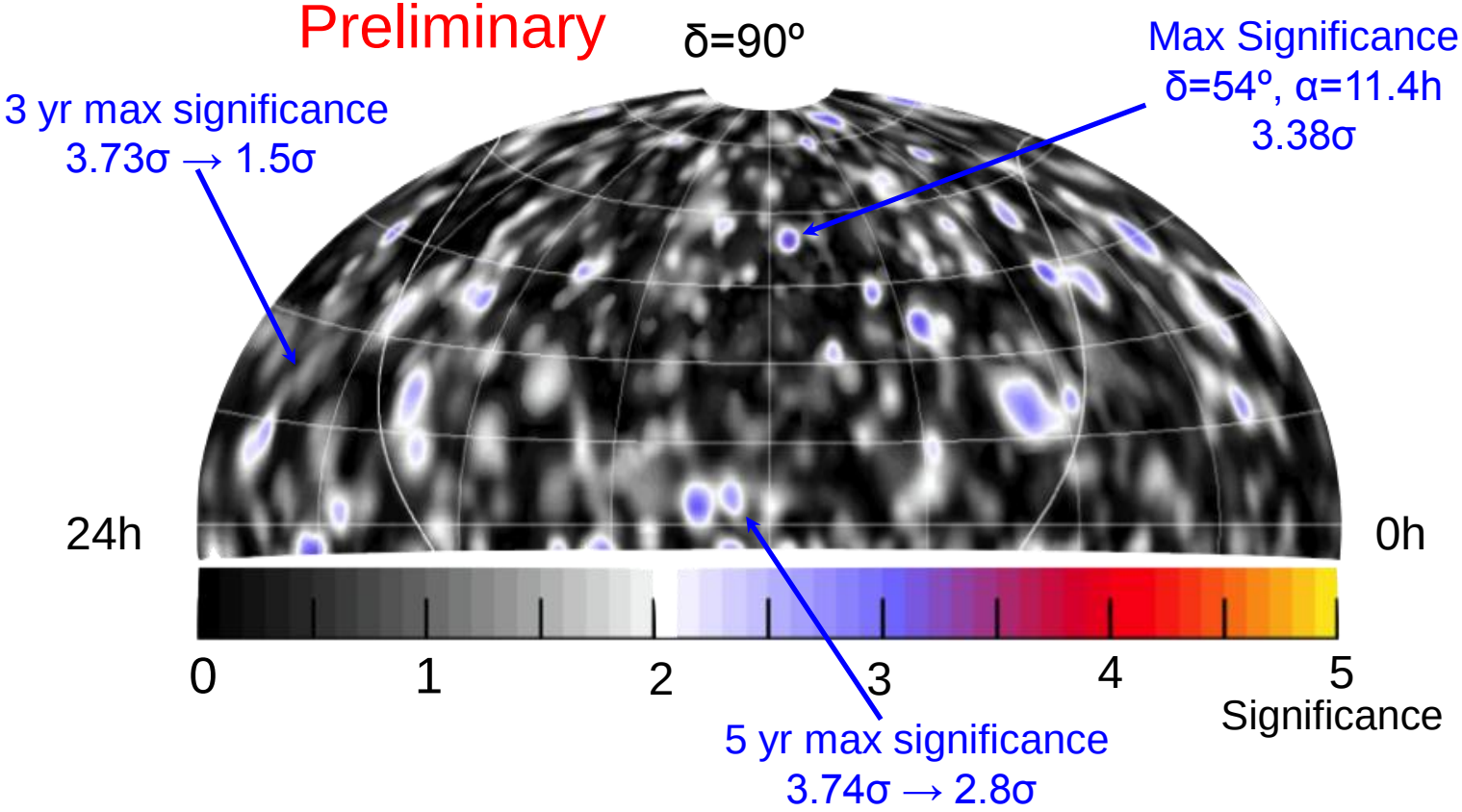
Search circle: 2.25-3.75 deg.

Angular resolution: 1.5-2.5 deg.

Search for clustering in northern hemisphere
- compare significance of local fluctuation to atmospheric ν expectations

2000-2006 6595 events

Preliminary



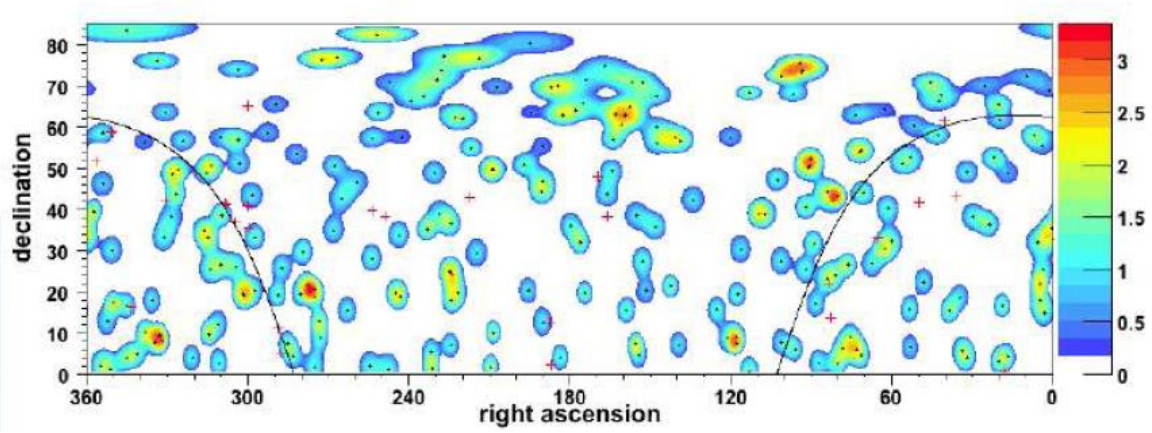
Point source search by IceCube

IC-9

233 ν in 137 days

Consistent with atmospheric ν

No signal



IC-22

~5000 ν in 250 days

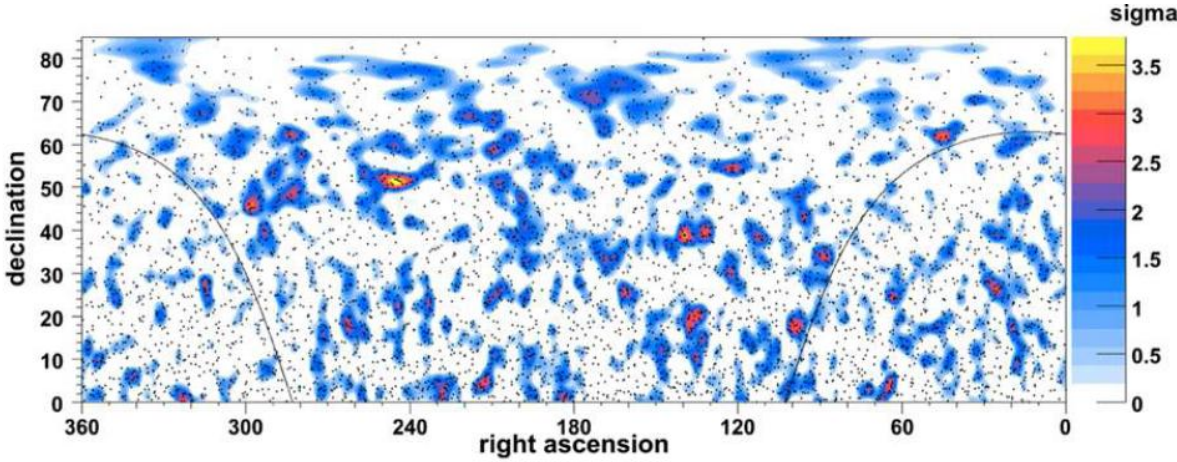
Resolution 1.5 deg.

5 times better sensitivity than IC-9

(Better than AMANDA 5 years!)

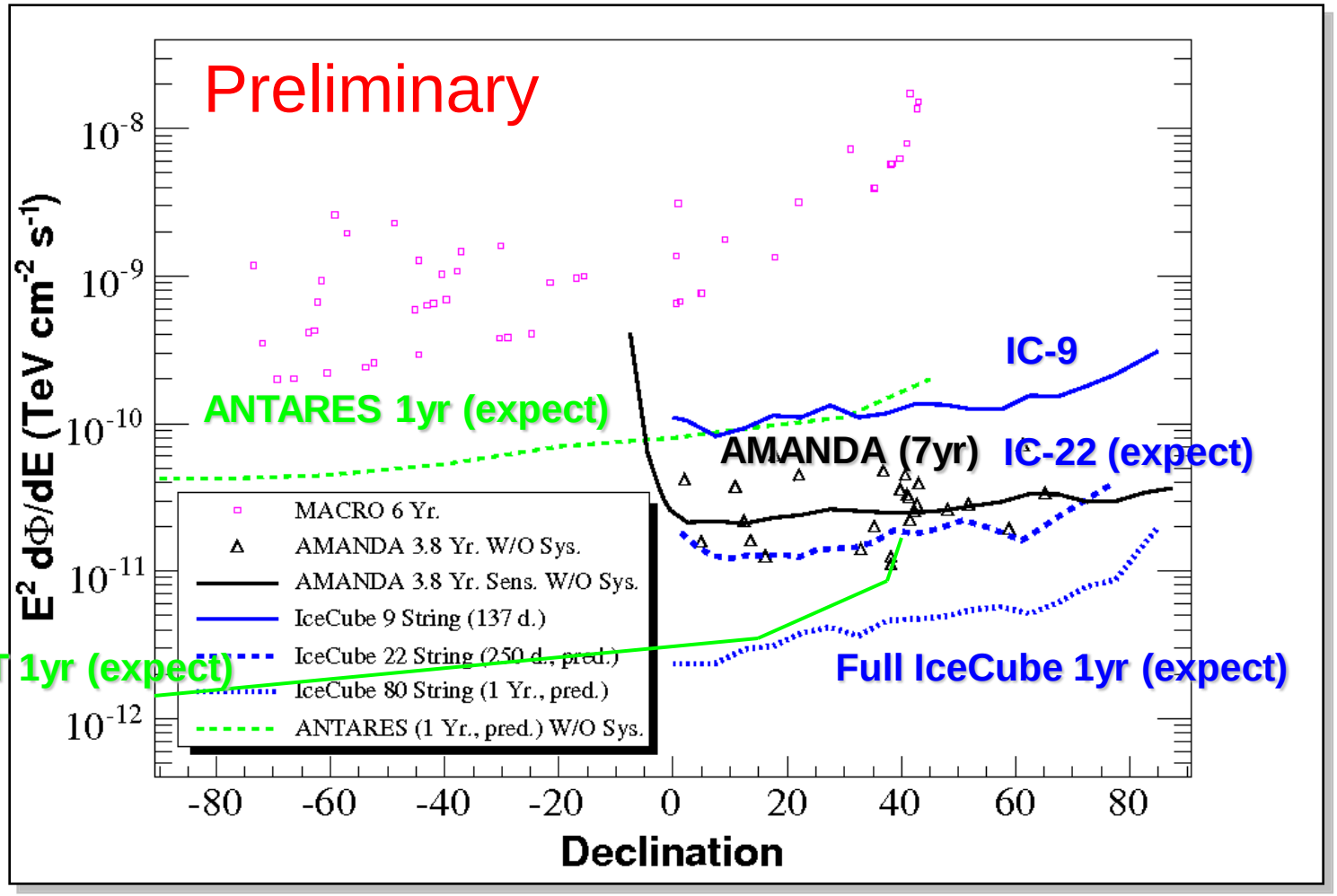
Soon to open the blinded box

Diffuse result is also coming



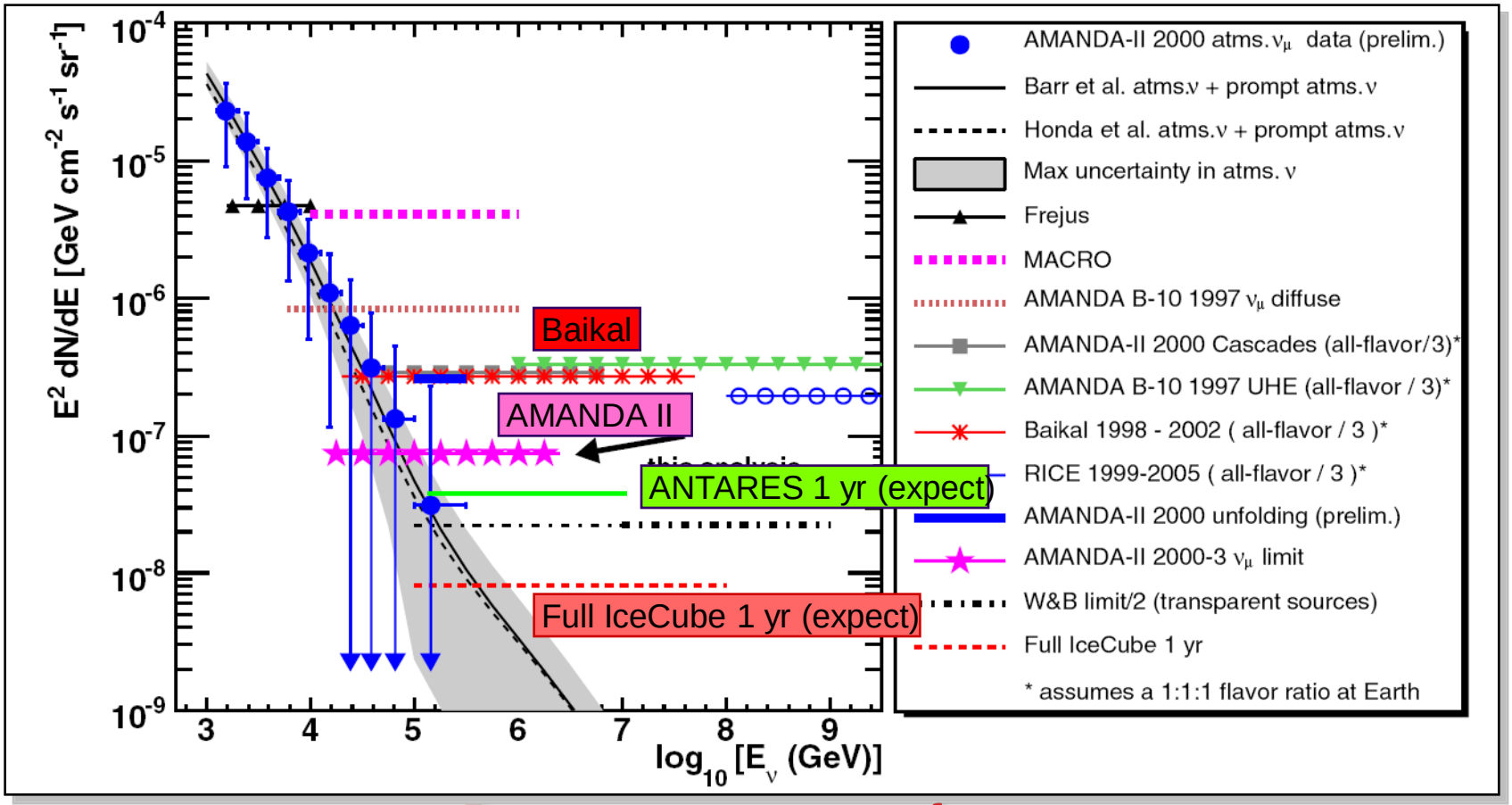
Scrambled in right ascension

Point source sensitivity



Diffuse neutrinos

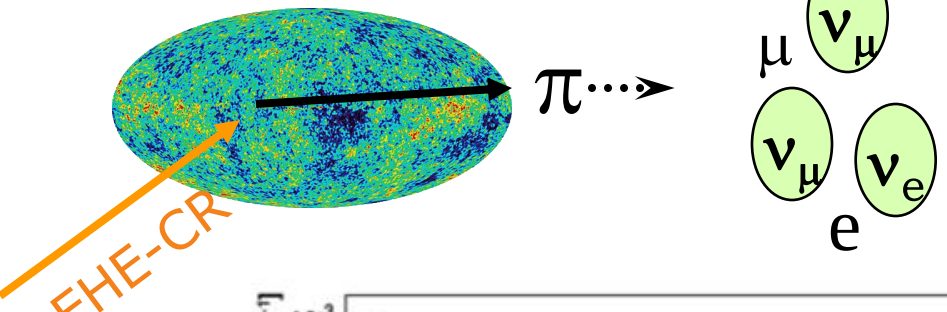
Even though we can't resolve signals from each source, we can integral signals in all sky and should see some excess.



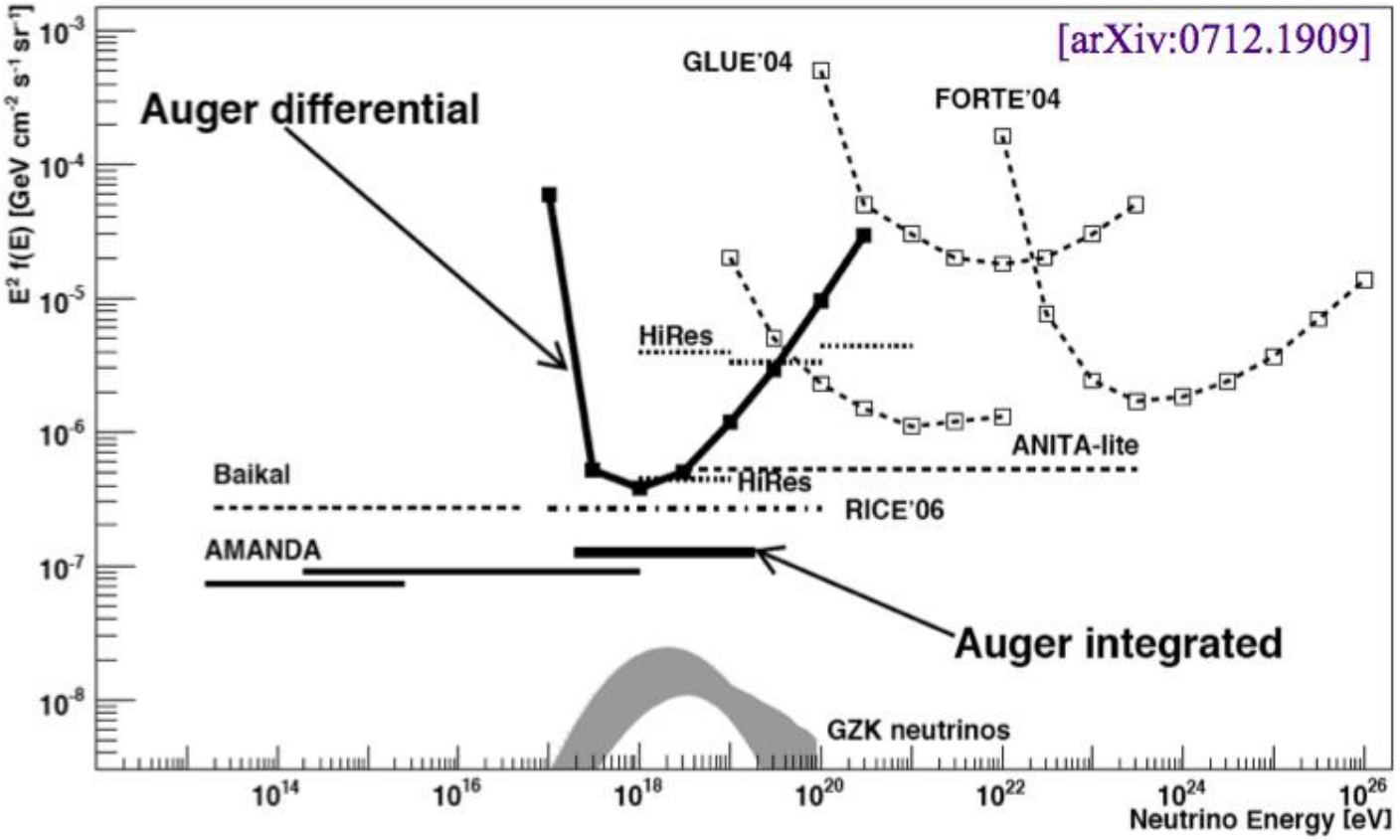
But, no excess so far

The cosmogenic neutrinos

$$p\gamma_{2.7K} \rightarrow \pi^{\pm} + X \rightarrow \mu^{\pm} + \nu \rightarrow e^{\pm} + \nu's$$

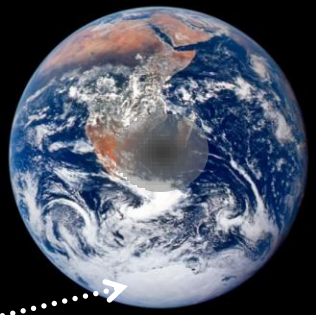


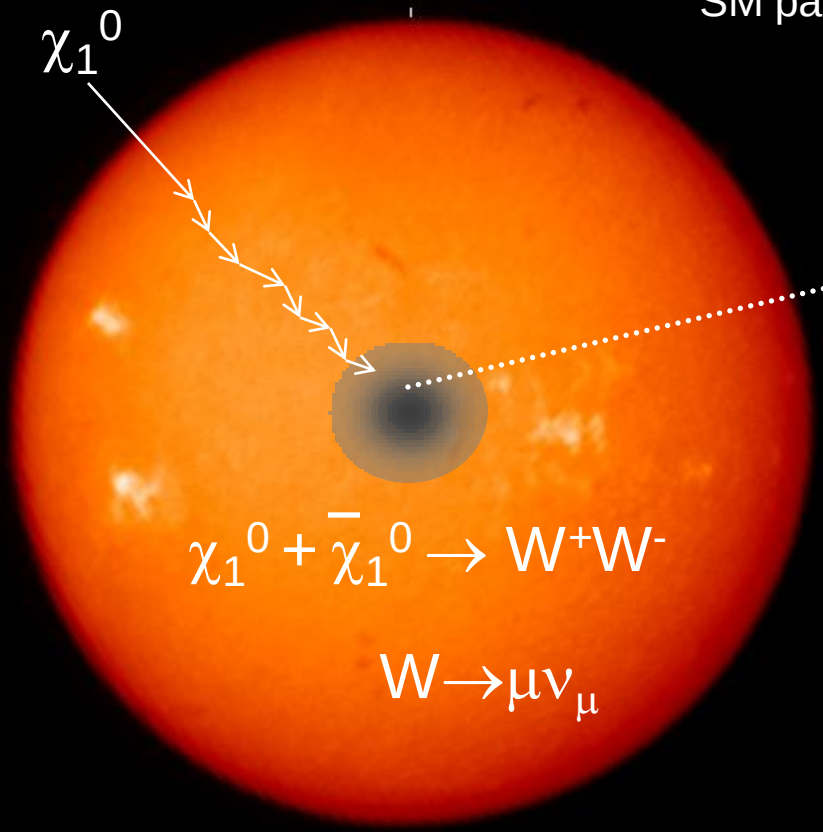
"guaranteed source"



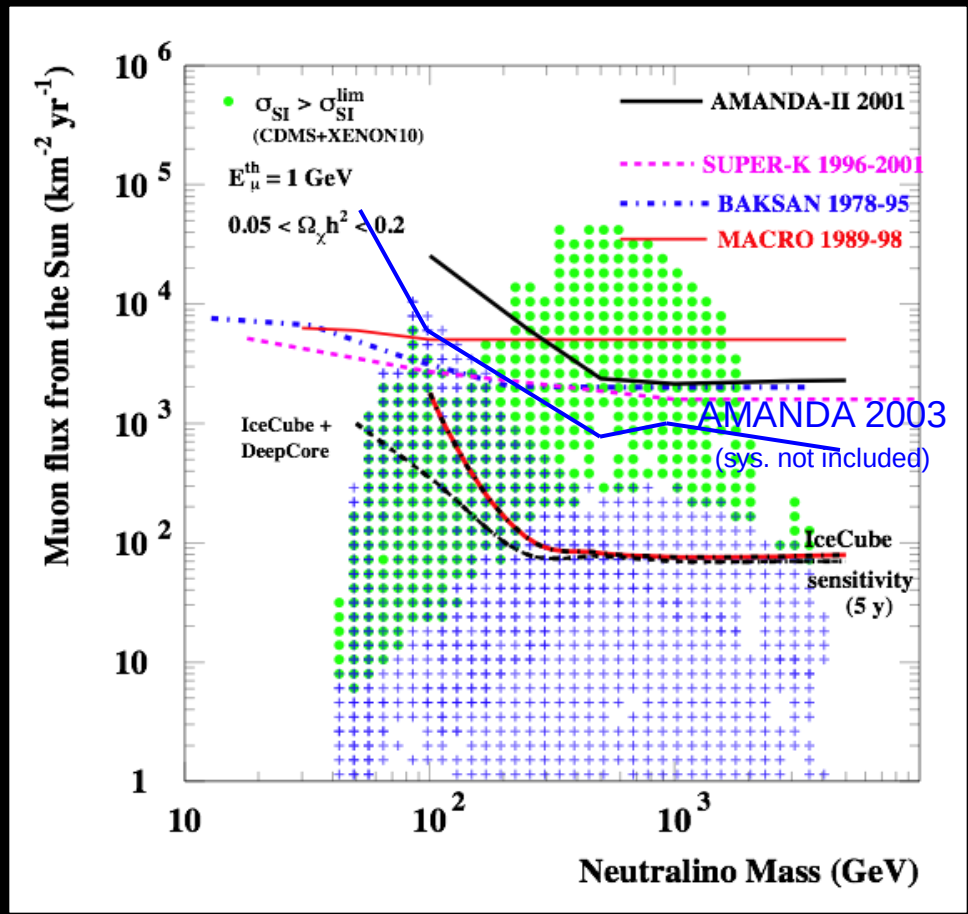
❑ WIMP Search

Neutralino scatters and loses energy
Becomes trapped in gravity well
Annihilates to pairs of SM particles
SM particles decay producing n



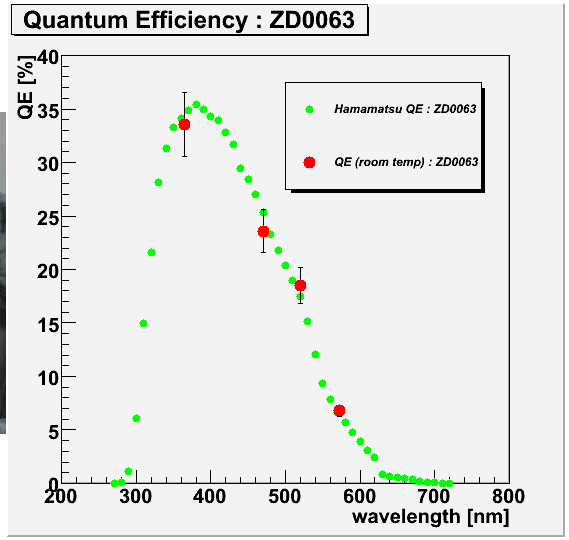


$\chi_1^0 + \chi_1^0 \rightarrow l^+l^-, q\bar{q}, W^+W^-, Z^0Z^0$
$\chi_1^0 + \chi_1^0 \rightarrow H^0_{1,2}\, H^0_3, Z^0H^0_{1,2}, W^+H^-, W^-H^+$

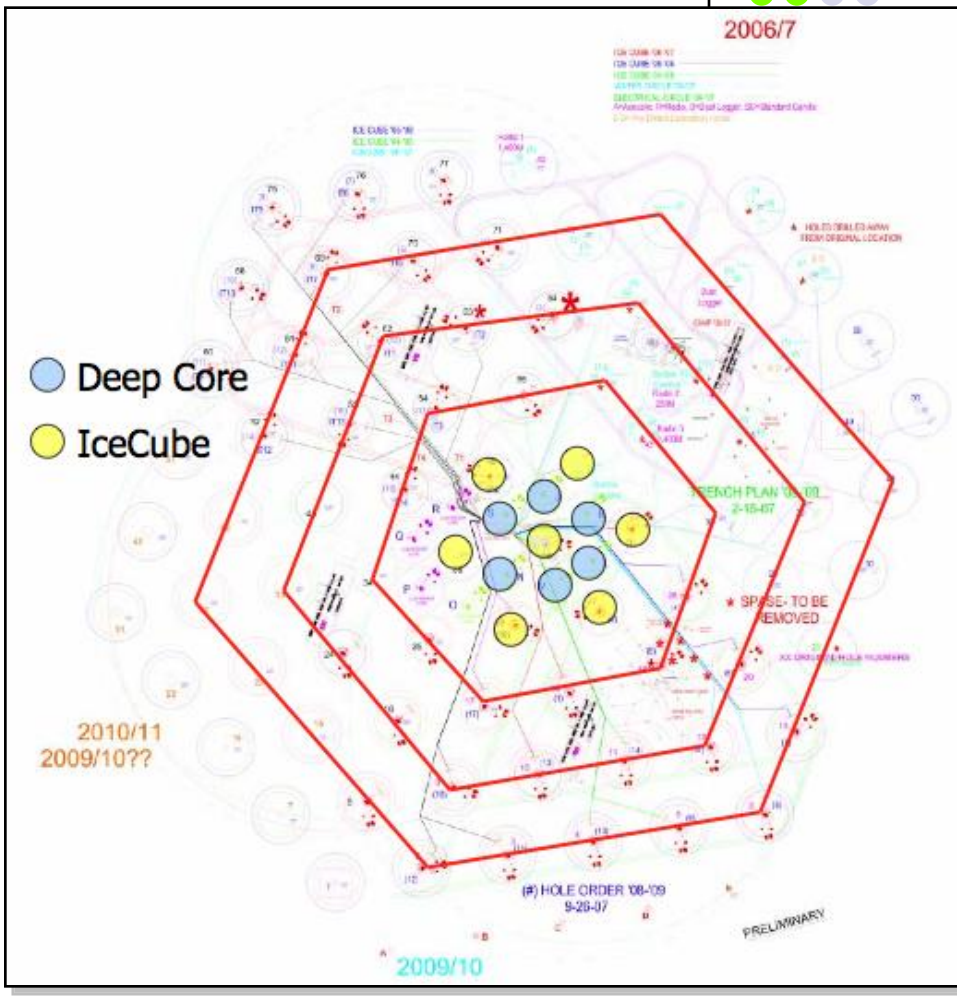


IceCube Deep Core

- Extend IceCube sensitivity to neutrinos with energies below a few hundred GeV
  - Replacement for AMANDA
  - Six strings with 60 high-QE PMTs each (HAMAMATSU super bialkali)
  - Use very clear ice at bottom of IceCube
- Already budgeted



Measured at Chiba Univ.

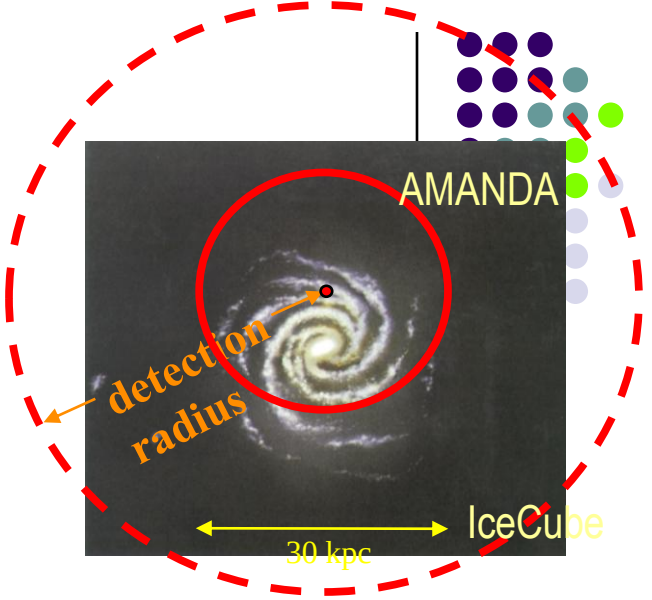


SN Neutrino Search

Bursts of low-energy (MeV) neutrinos
from core collapse supernovae

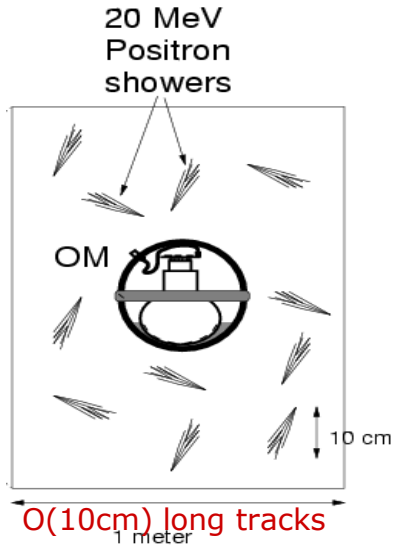
$$\bar{\nu}_e + p \rightarrow n + e^+$$

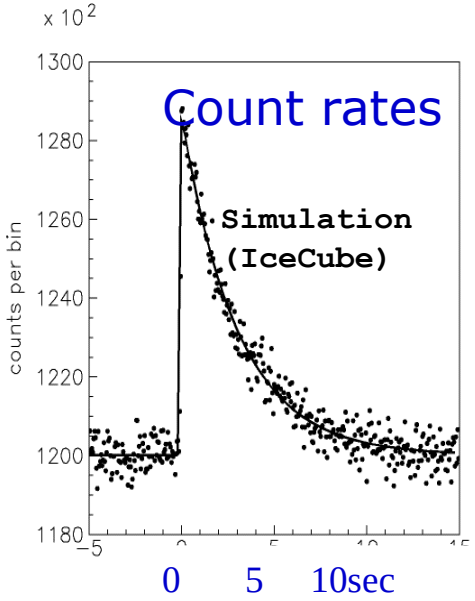
The produced positron is emitted almost isotropically



- AMANDA sees 90% of the galaxy
- IceCube will see out to the LMC
  (Large Magellanic Cloud, ~50 kpc)

Detection via rate increase of the dark noise rate





Record noise rate in 500 ms (~6×10^5 event/bin, stat. err. very small)

No pointing, no energy

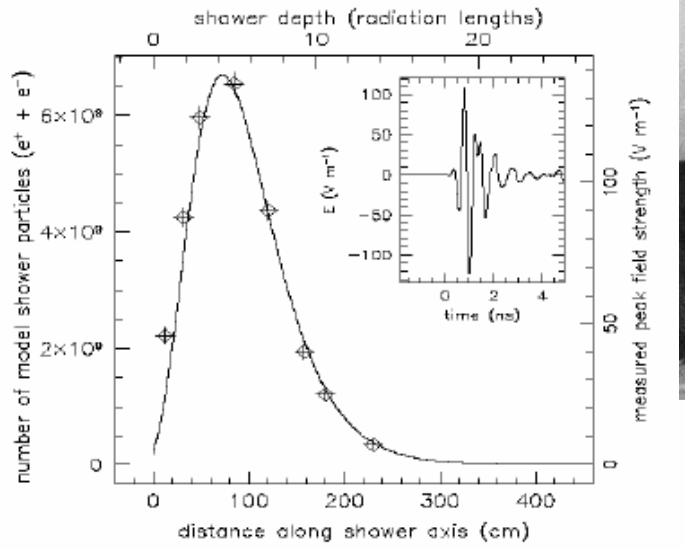
SNEWS (SuperNova Early Warning System) is a collaborative effort among Super-K, SNO, LVD, KamLAND, AMANDA, BooNE and gravitational wave experiments

Radio detectors

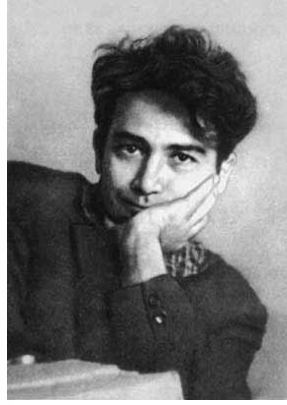
- 1962: Askaryan predicted coherent radio emission from excess negative charge in an EM shower (~20% due to mainly Compton scattering)

Askaryan effect

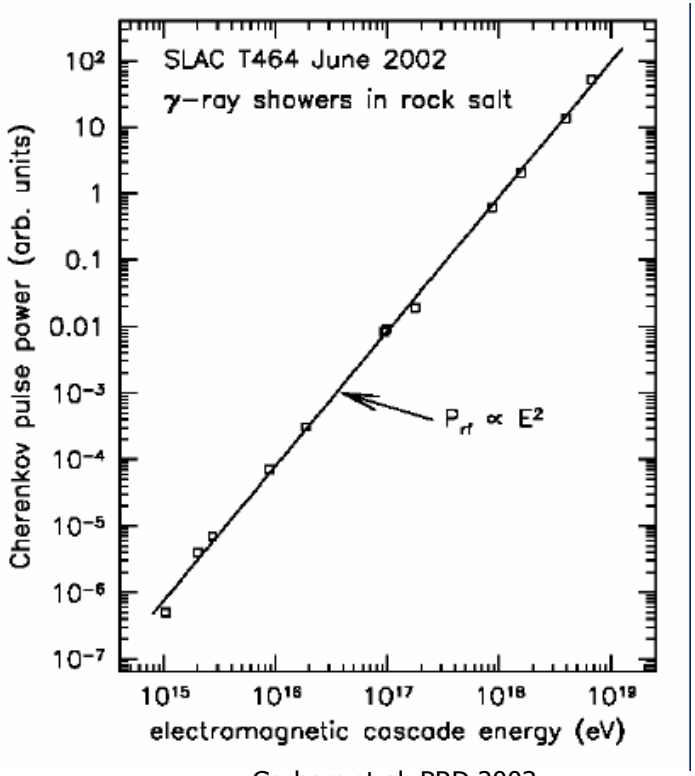
- 2001: confirmed at SLAC



Saltzberg& Gorham et al. PRL 2001



- several experiments to detect EHECRs using Askaryan effect:
  - Parkes 64 m dish
  - RICE
  - GLUE
  - 64m Kalyazin telescope
  - FORTE
  - ANITA



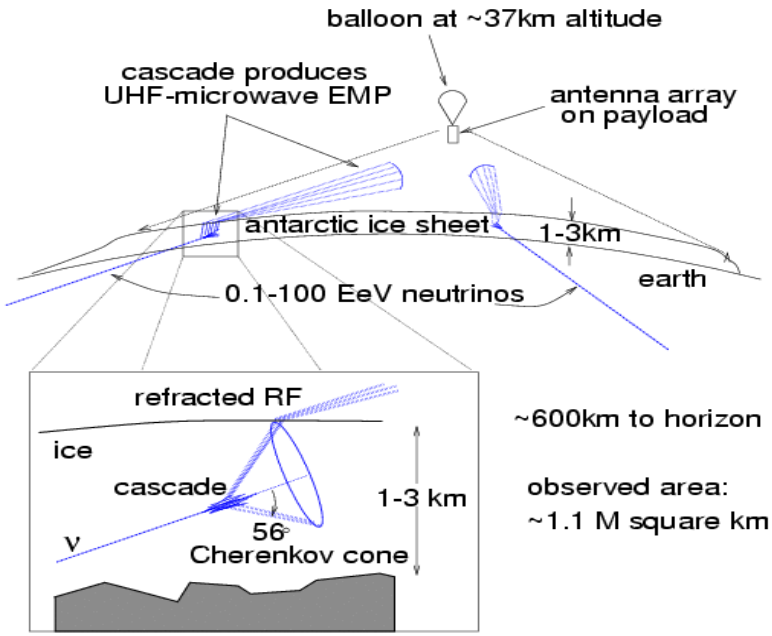
Gorham et al. PRD 2003

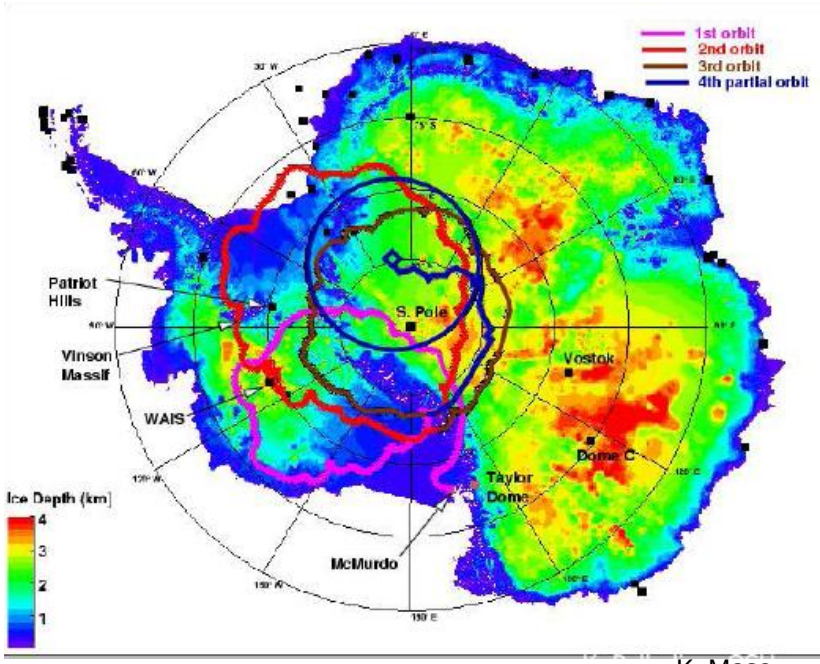
ANITA (Antarctic Impulsive Transient Antenna)

- detect radio wave from showers using Askaryan effect
- view: 1.5 M km^2 ! (Tokyo-Hakata: 880km)
- sensitive: 0.2-1.2 GHz
- 2003-4: ANITA-lite (2 hones)
- 2006-7: full ANITA

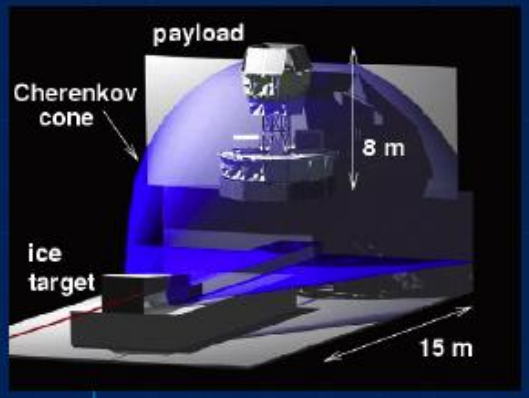
  35 days, 3.5 orbits, good data: ~10 days
- 2008-9: ANITA 2

  x5 event rate (by mainly lowering the threshold)





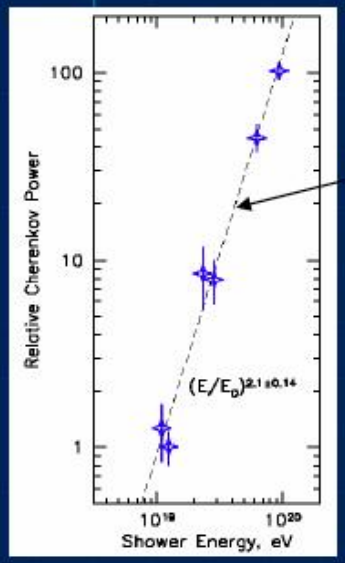
June 2006, SLAC T486: "Little Antarctica"

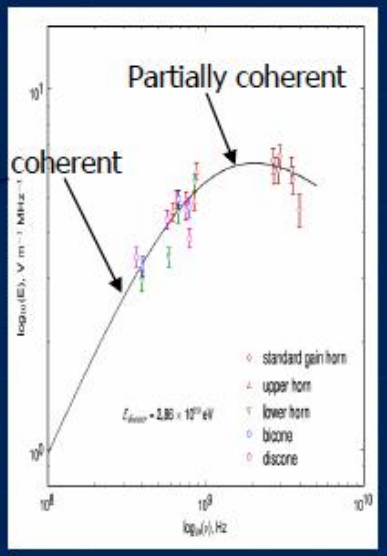


End Station A, SLAC

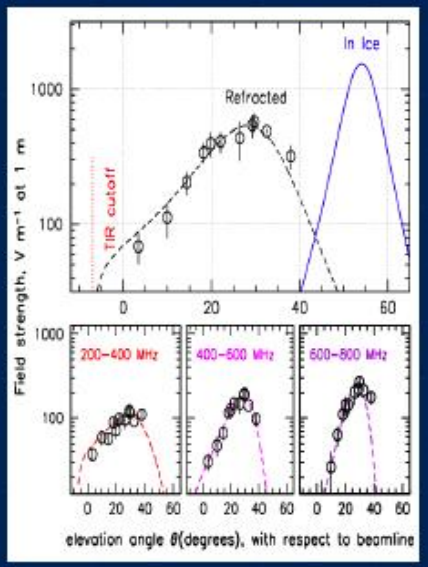
Thanks to P. Chen, C. Hast, SLAC

- SLAC e^- showers with composite energy same as UHE neutrinos
  - $10^{8\text{-}9}$ x 28 GeV = 2.8 x 10^{19} eV



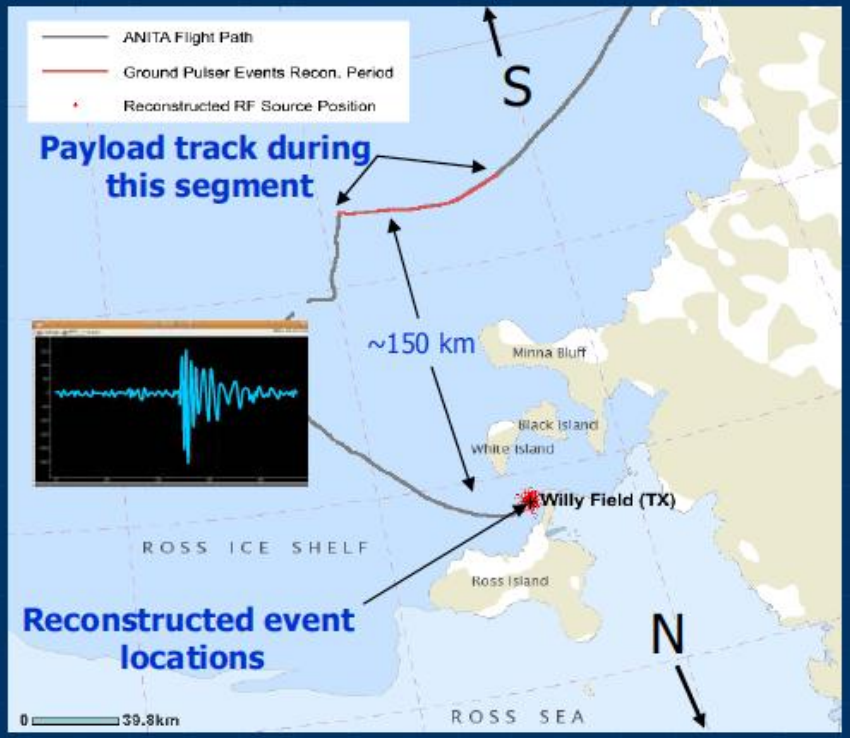


- Coherent radio power consistent with theory

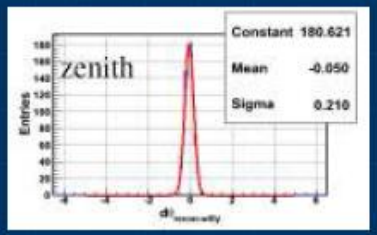


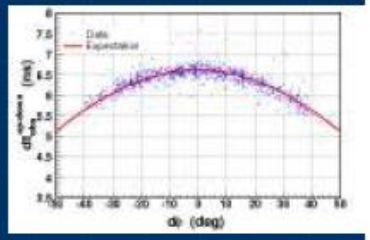
- 1st direct observation of radio Cherenkov cone

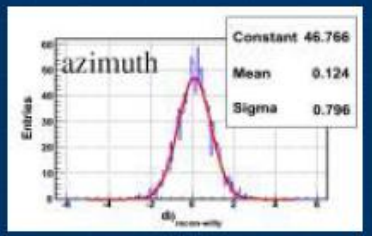
ANITA geo-location of borehole cal events

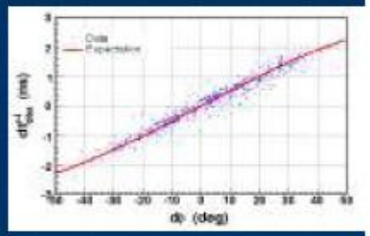


- Expect ~ $c\Delta\tau$/2D altitude & azimuth
- $\Delta\tau$ ~ 40-60 ps, D ~ 1m (horizontal) to 3 m (vertical)
- Altitude: 0.21° observed, 0.3° expected
- Azimuth: 0.8° observed, 1.7° expected
- Multiple baselines improve constraints
- Pulse-phase interferometry works well!

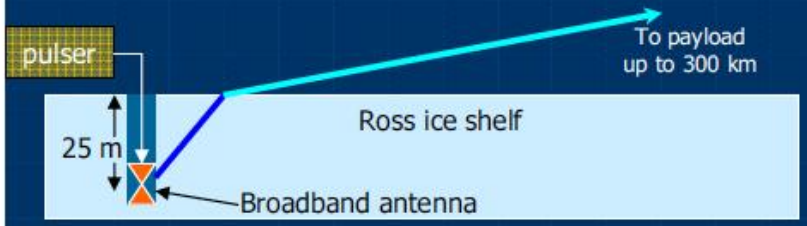








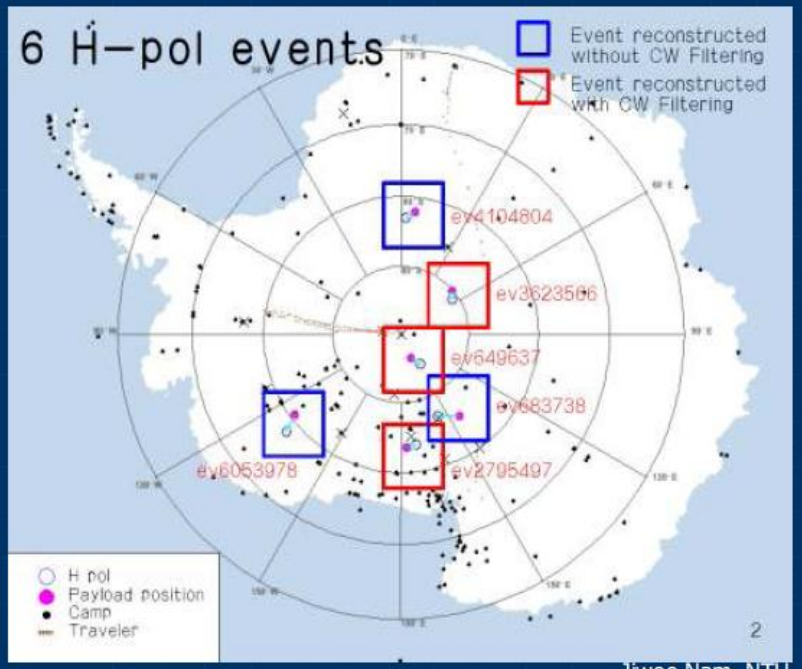
Thanks to JiWoo Nam, NTU



P. Gorham, Neutrino 2008

17 of 25

Initial unblinded higher-threshold event set



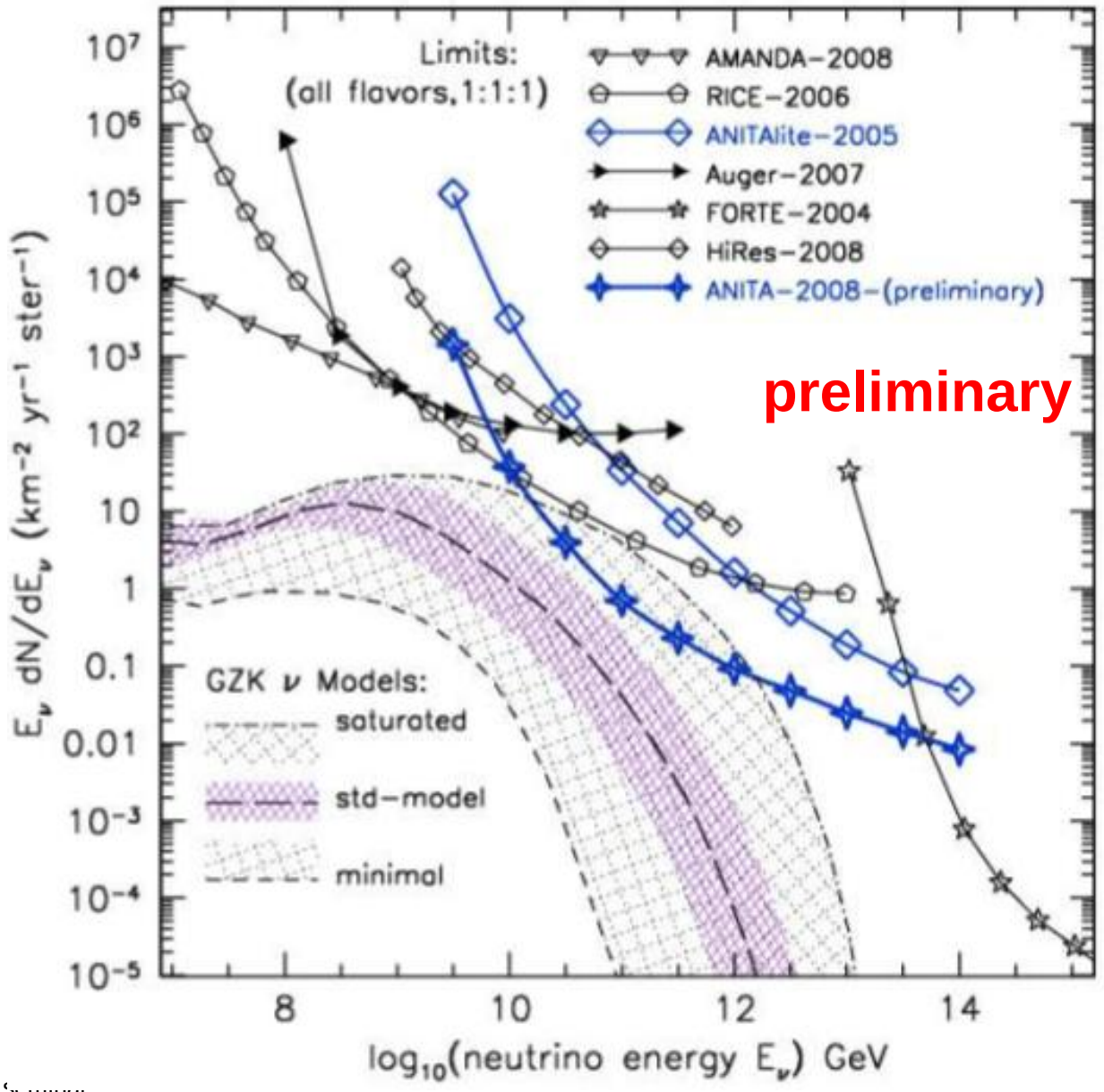
Jiwoo Nam, NTU

- ~19K events (9.6K Vpol & 10K Hpol) are impulsive & reconstruct to Antarctic ice locations
- Exclude all repeating locations (H,V,H+V)
- Exclude single events within ~50km from known sites
- After cluster+camp rejection:
  - 0 V-polarized (no askaryan-like signals➔ no neutrinos)
  - 6 H-polarized events left

"camp" = any man-made installation, active or not
- most are inactive, many may be gone in fact
- but exposed metals could discharge

- Askaryan (eg, neutrino) signals strongly favor vertical polarization
  - Only top quadrant of Cherenkov "clock-face" escapes TIR at surface
  - Fresnel coefficient transmits more Vpol (TM) than Hpol (TE)
- Reflections from above-the-horizon sources tend to strongly favor horizontal polarization
- R_{TE}/R_{TM} > 3:1 over most of ANITA acceptance
- ➔ Hpol events cannot be neutrino candidates but could be
  - Air shower radio (geo-synchrotron)
  - Solid-state relays on satellites

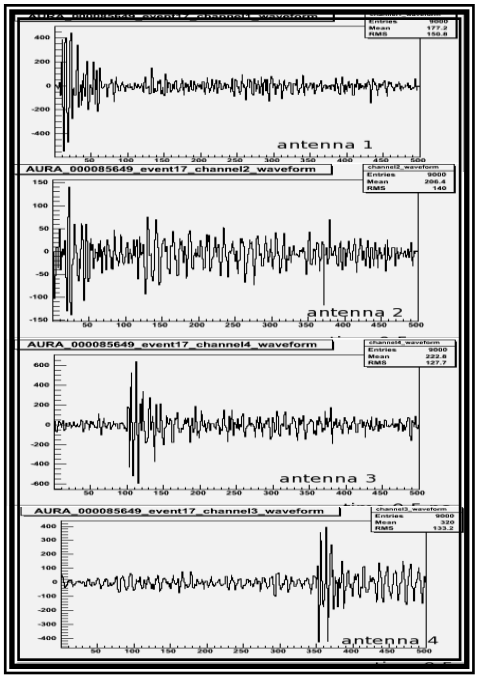
ANITA sensitivity



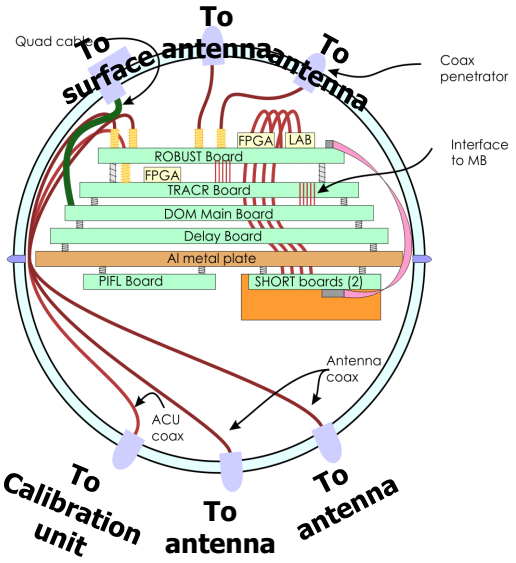
AURA (Askaryan Uunder ice Radio Array)

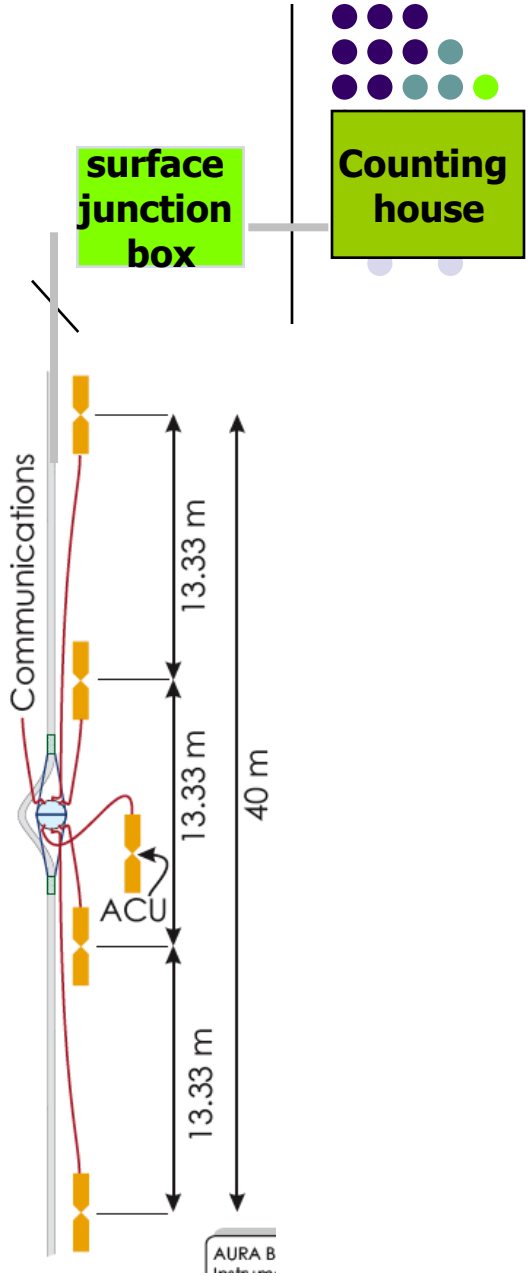
- 3 DRMs (digital radio module) deployed (2006-7) in ice at IceCube site
- broad dipole antena centered at 400 MHz
- The R&D is in progress

A signal candidate



Digital radio module





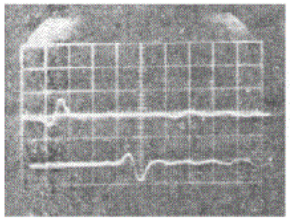
Acoustic Detectors

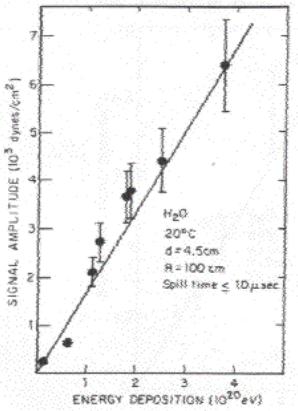
A pressure wave is generated instantaneous following a sudden deposition of energy in the medium (neglecting absorption: O(10 km) at 10 kHz)

Accelerator Experiments: results and open questions

Brookhaven NL (Harvard, SLAC) 1979

200 MeV proton beam (LINAC)
Spill time 3 to 20 us
Beam diameter 4.5 cm
Energy deposited in water $10^{19} \rightarrow 10^{21}$ eV
Bipolar pulses observed
Dependency on C_p, T and on beam diameter confirmed (about 10% uncertainty)



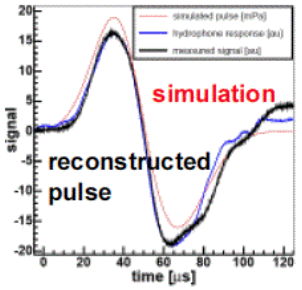


Recent measurements (2000's)

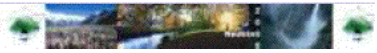
Uppsala: 177 MeV p
E= 10^{16} – $10^{17.5}$ eV
Bipolar pulse observed
Unclear dependence on temperature
Other contibution to observed pulses ?

ITEP Synchrotron: 100, 200 MeV p
E= 10^{15} – 10^{20} eV
Measured pressure increses linearly with E

Erlangen Laser Nd-YaG
E= 10^{17} – 10^{19} eV
Dependence on C_p confirmed

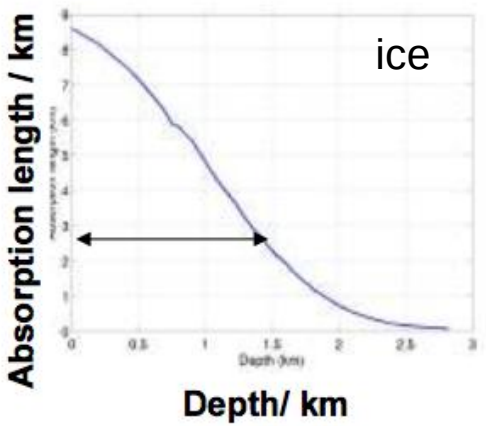


Giorgio Riccobene INFN LNS

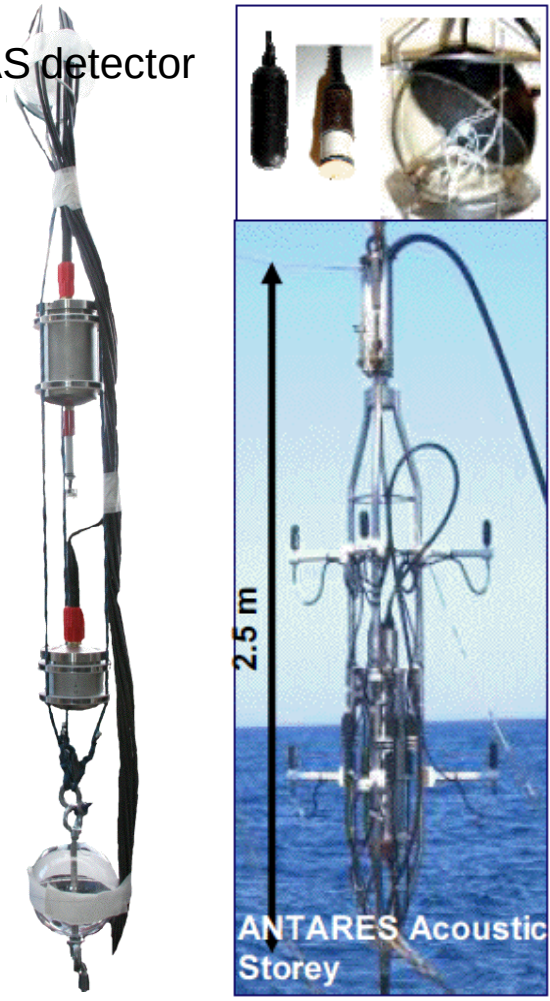


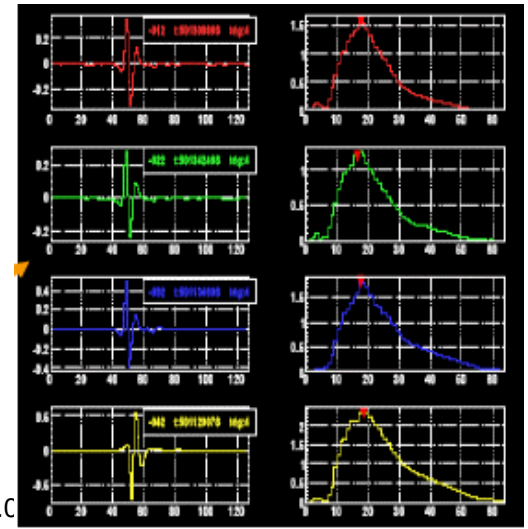
Acoustic Detectors (cont'd)

- There are many R&D for the use
  - SPATAS (@ IceCube)
  - SAUND
  - ACORNE
  - AMADEUS (@ ANTARES)
  - NEMO-OnDE (@ NEMO)
  - @Baikal
- measuring the midium property and noise.
- effort to reconstruct events



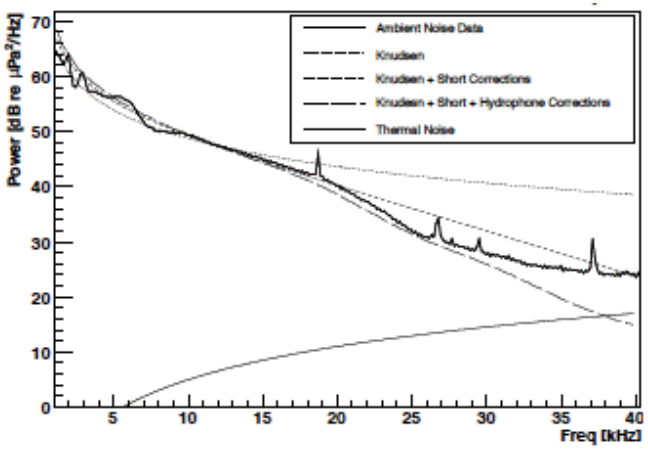
SPATAS detector





Measured event by ACORNE

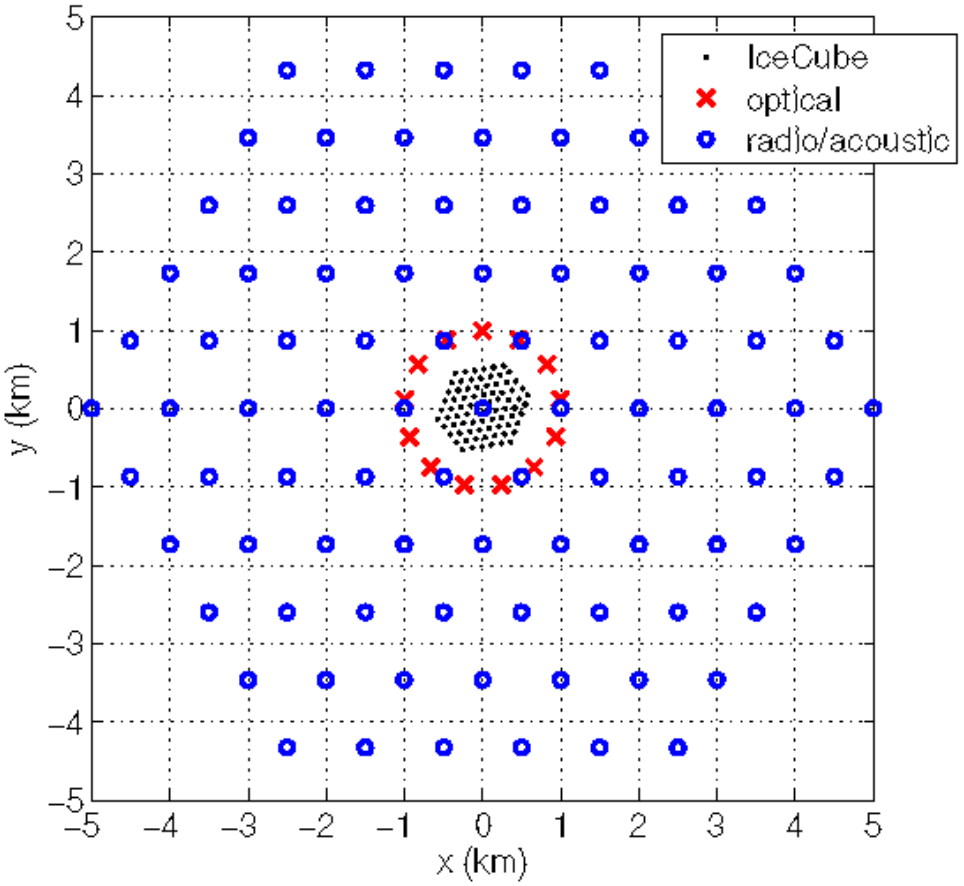
Measured noise by SAUND



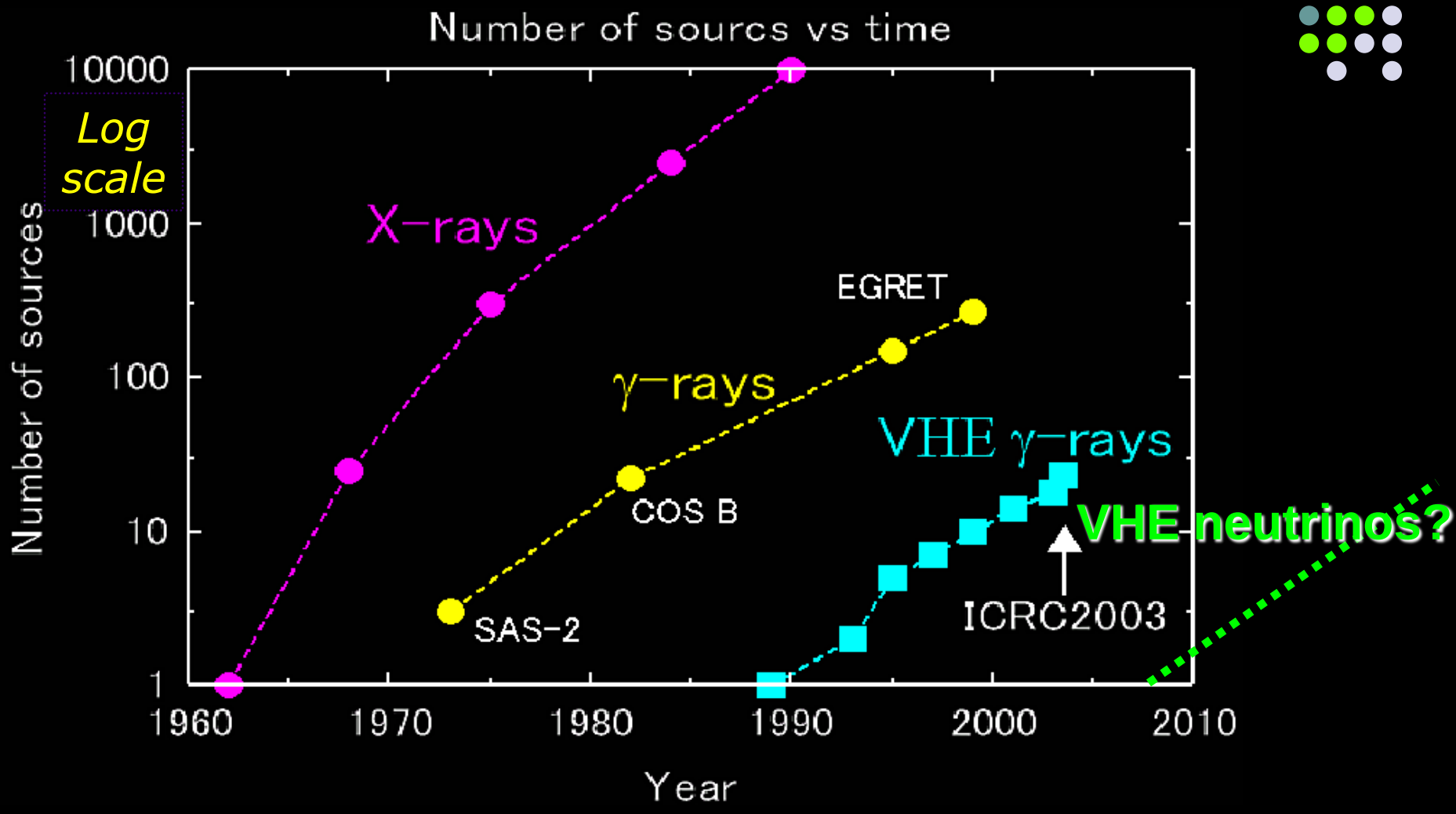
Hybrid Detector

Hybrid IceCube+Radio+Acoustic (IRA)

- ~100 km^3 effective volume at GZK energies
- ~100 strings on 1 km spacing grid



How Kifune plot will be for VHE neutrinos?



"Kifune plot" ©Rene Ong 2002

Summary

- Very high energy neutrinos should be generated where the cosmic rays are generated.
- One neutrino source will open the astronomy.
- A 1 km^3 detector can possibly detect it. (reaching the WB limit)
- A detector having a larger effective volume is more feasible to detect. The efforts are being made for such detectors.

Who will open it?