IceCube:
Science Goals & Current status

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IceCube

***P**enn **S**tate **U**niv.*

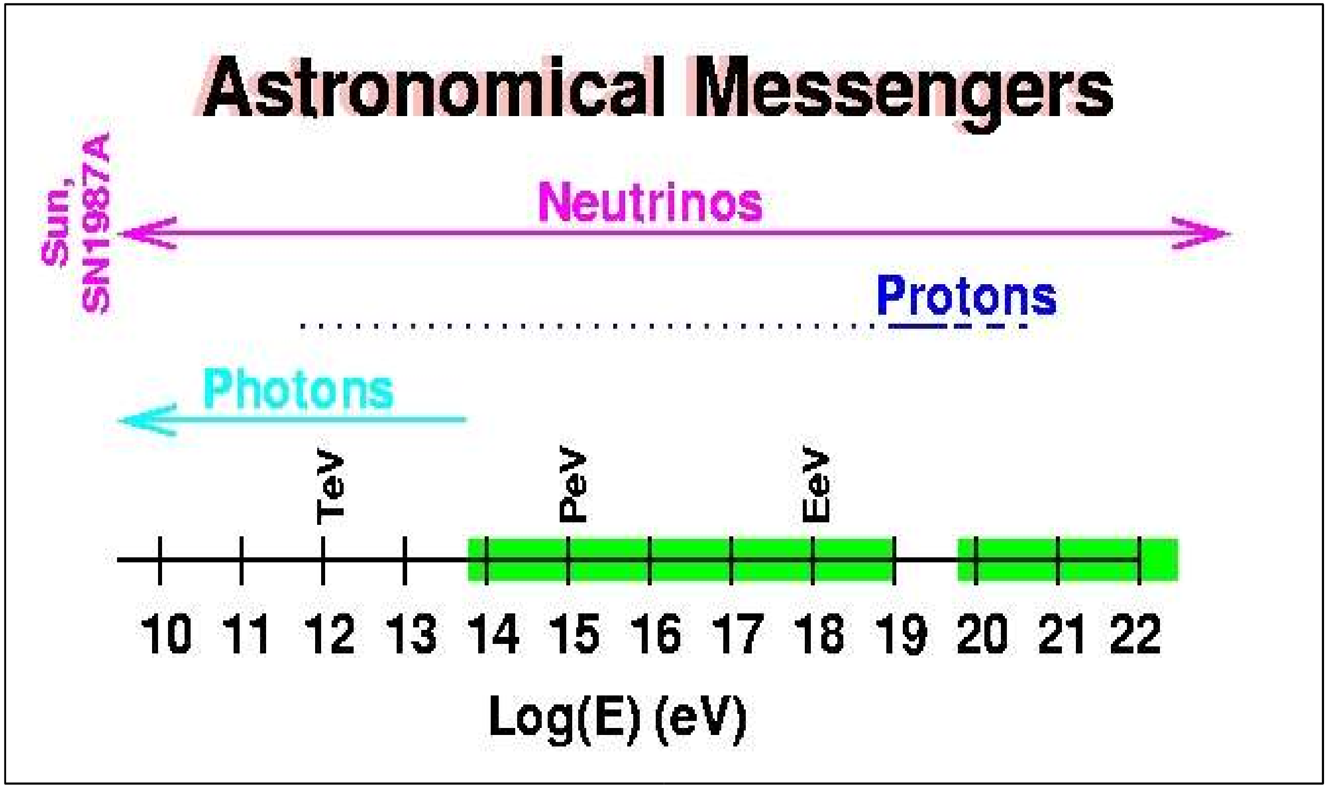
KIAS-APCTP-DMRC Workshop
"The Dark Side of the Universe"
5/24 – 5/26, 2005
KIAS
Seoul, Korea

Outline

- Neutrino Astronomy
- IceCube Detector
- Science Goals (w/ AMANDA results)
- Indirect WIMP Search
- Current Status
- Summary

Neutrino Astronomy

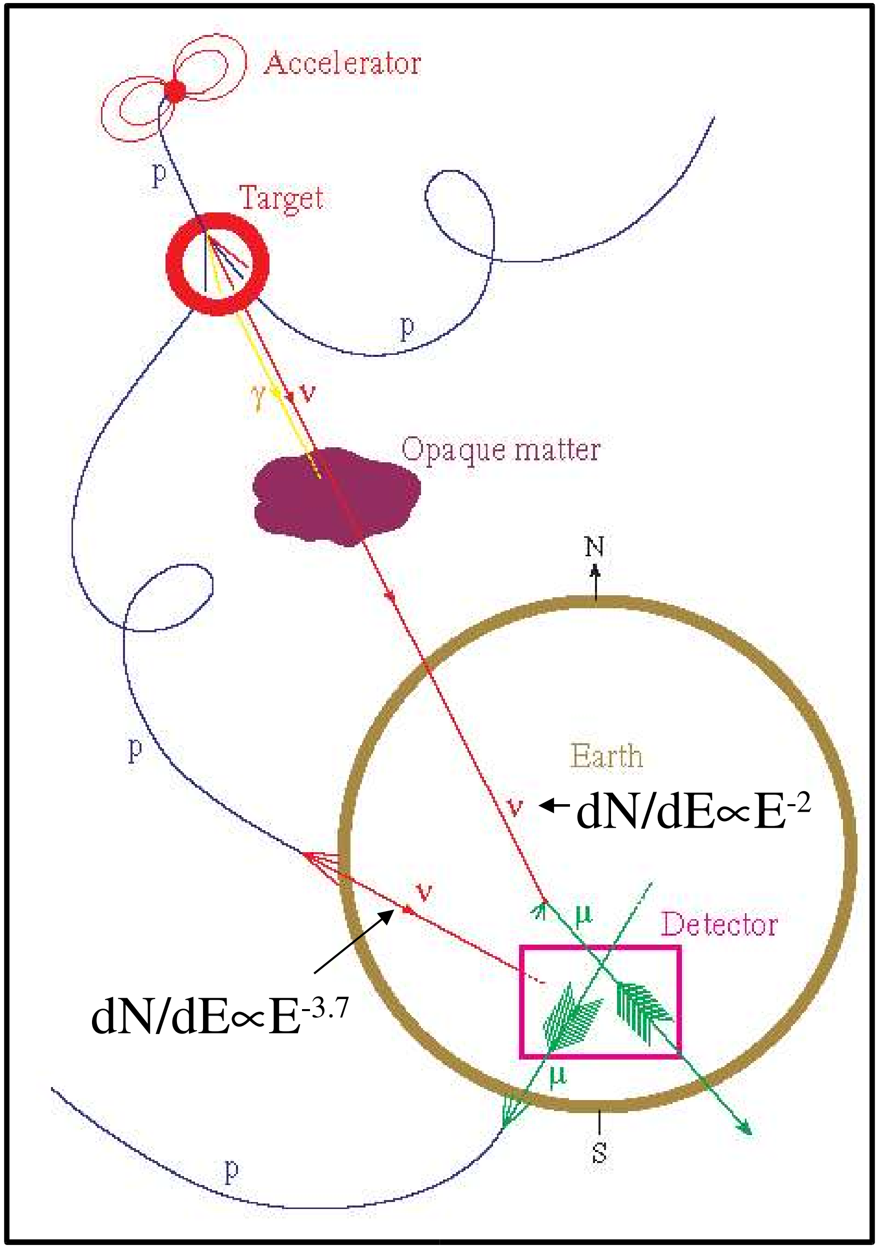
Why neutrino...?



Neutrinos point back to its source unlike protons.

Neutrinos don't get scattered/absorbed unlike photons.

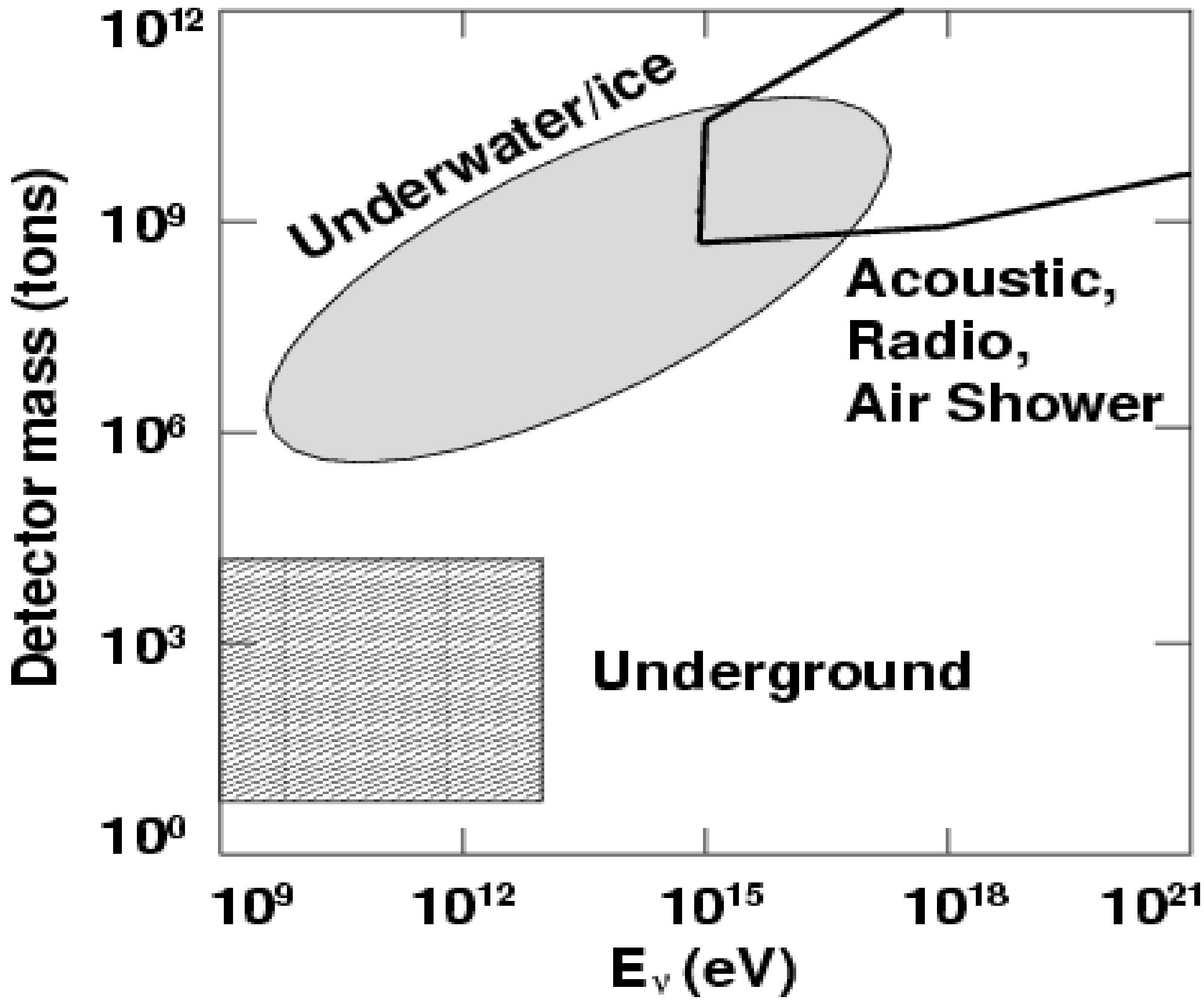
Neutrino Astronomy



- **Atmospheric** ν :
  -- $dN/dE \propto E^{-3.7}$ (E_ν > 1TeV)
  -- prompt nu (E=1~500TeV) from charmed meson
- **Solar atmospheric** ν :
  -- $dN/dE \propto E^{-2.7}$
  -- low rate: ~17 ν_μ /km2.yr (E_ν >100GeV)
  ~5 ν_τ /km2.yr
- **Galactic** ν :
  -- low density --> dN/dE similar to CR
  -- galactic flux exceed atm at E_ν > ~100TeV
- **Extra-galactic** ν :
  -- $dN/dE \propto E^{-2}$
  -- rate:
  (AGN, GRB, SNR....)
- **Other sources**: WIMP, monopole, etc...

Neutrino Astronomy

Physics reach of various types of detectors



Neutrino Telescope

- **Neutrino telescope:** envisioned by Greissen & Reinnes (1960).

  -- DUMAND (1st prototype, 1987) --> mid-90 (AMANDA,DUMAND II, Baikal, NESTOR)

  (AMANDA 1st prototype: 1991)

- **Extraterrestrial neutrino experiment requirements:**

  -- huge volume <-- small neutrino cross section: use nature

  -- optically transparent medium <-- optical detector: use water or ice

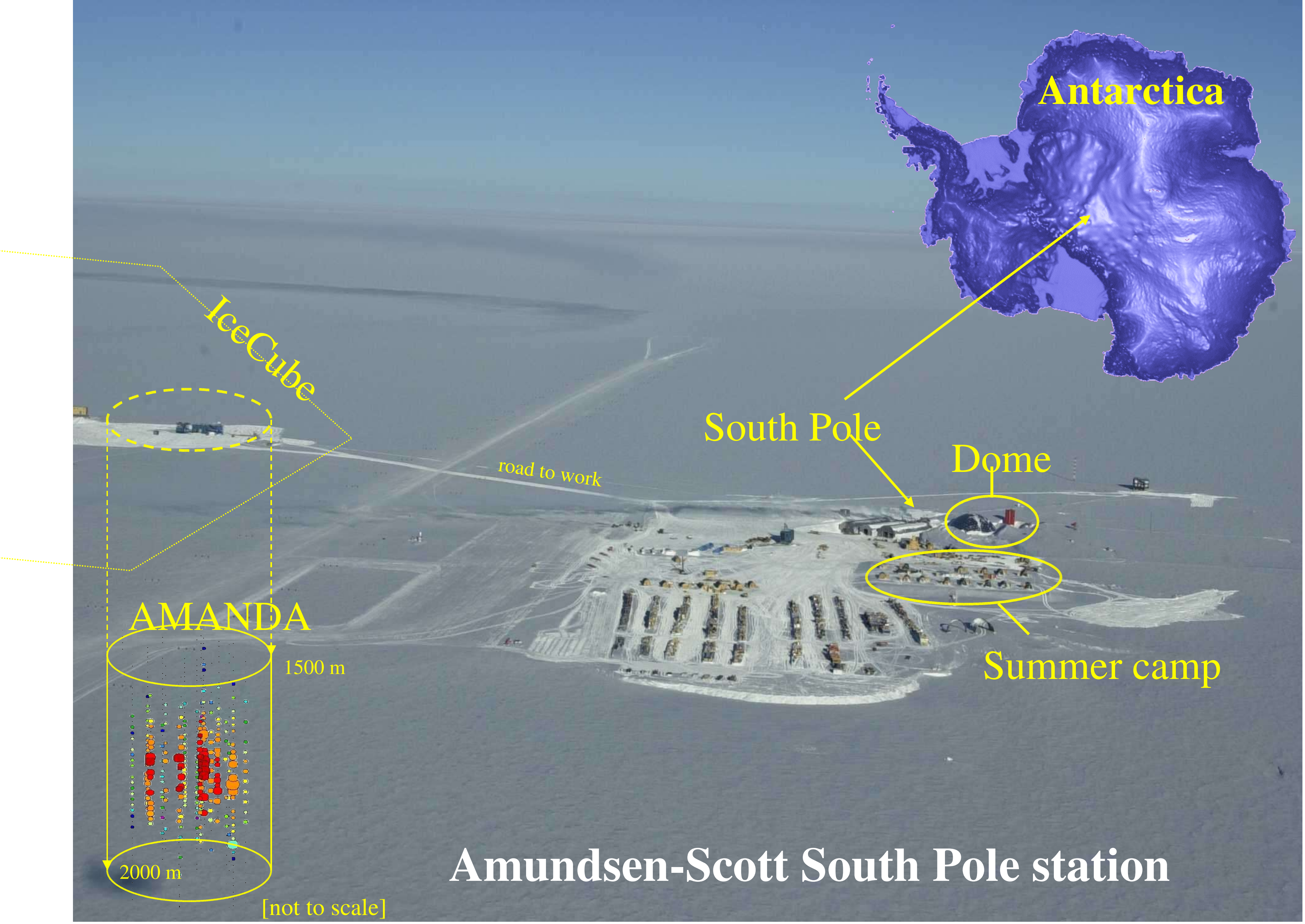
- **Neutrino telescopes in the world Now:**

  -- Water: NT-200 (Baikal), ANTARES, NESTOR, NEMO, KM3

  * pros: long scattering length (~ 100 m)
  * cons: short absorption length (~25-40m),
    BG from K decay, light emitting creatures, long cable length (~10-40 km)

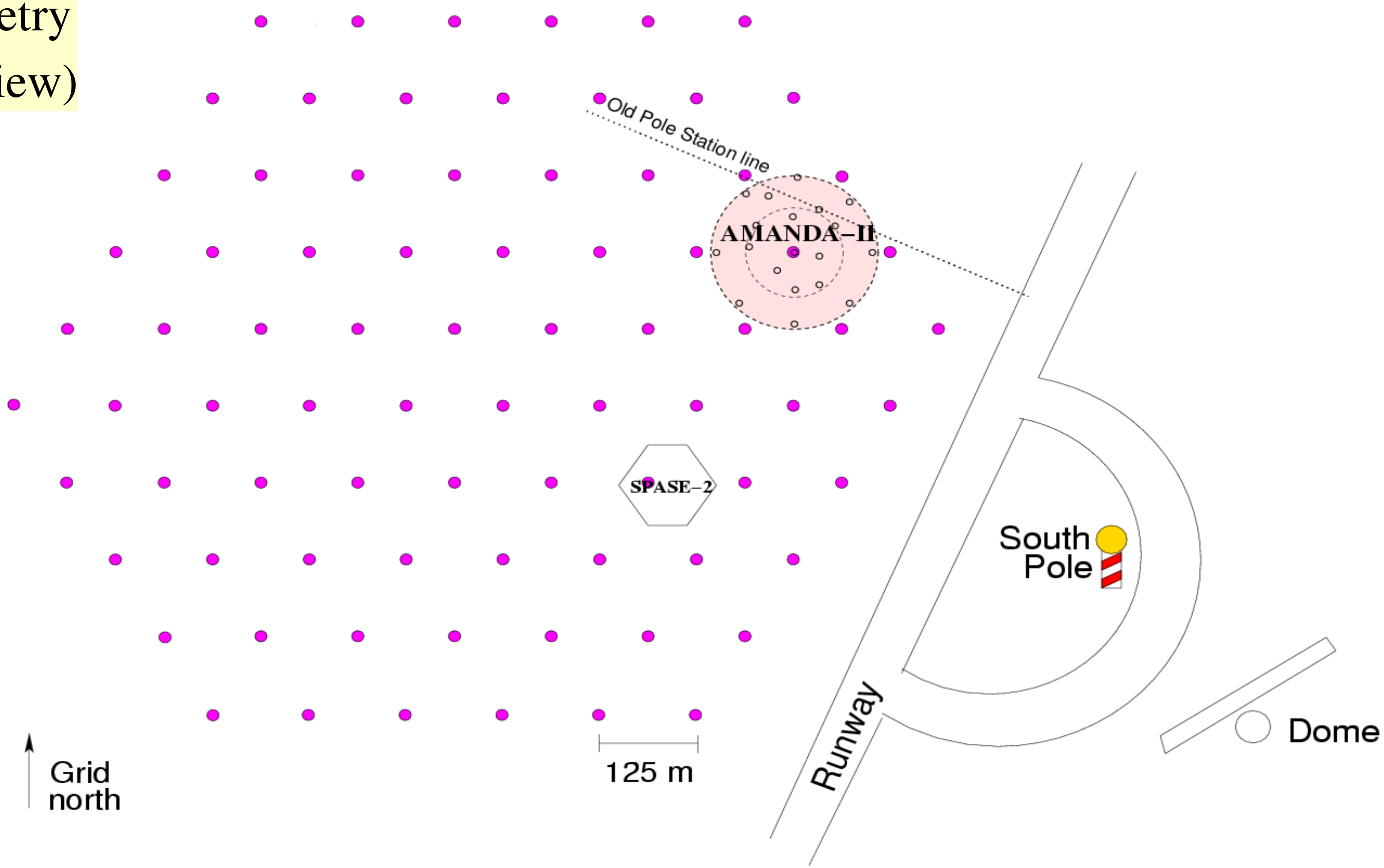
  -- Ice: AMANDA, IceCube (successor of AMANDA)

  * pros: long absorption length (~110 m @400nm), an order of magnitude lower BG
    hard surface (short cable length: ~3km), air shower array on ice top
  * cons: short scattering length (~20 m @400nm)

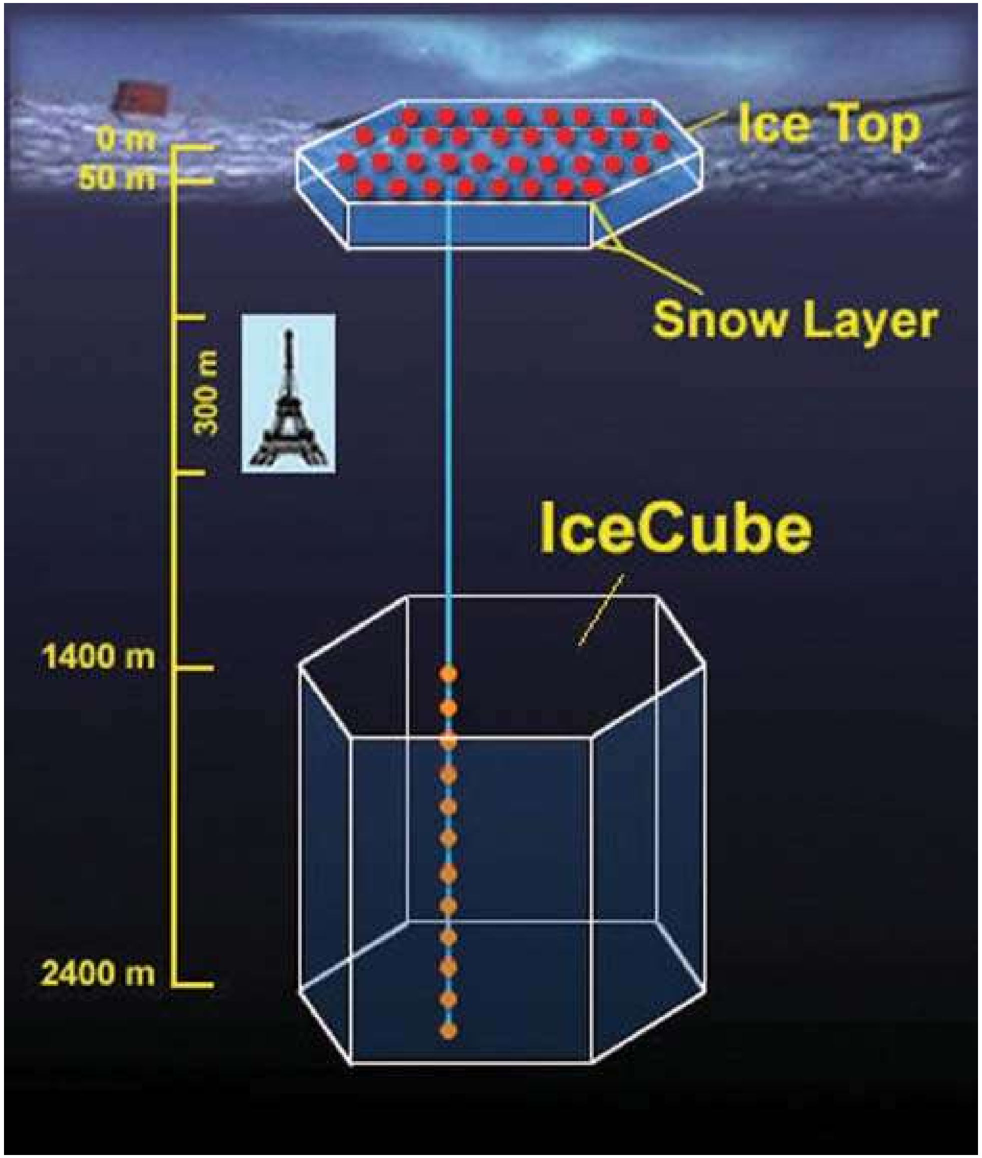

Antarctica
IceCube
South Pole
Dome
road to work
AMANDA
1500 m
Summer camp
2000 m
[not to scale]
Amundsen-Scott South Pole station

IceCube Detector

Geometry (top view)



IceCube Detector



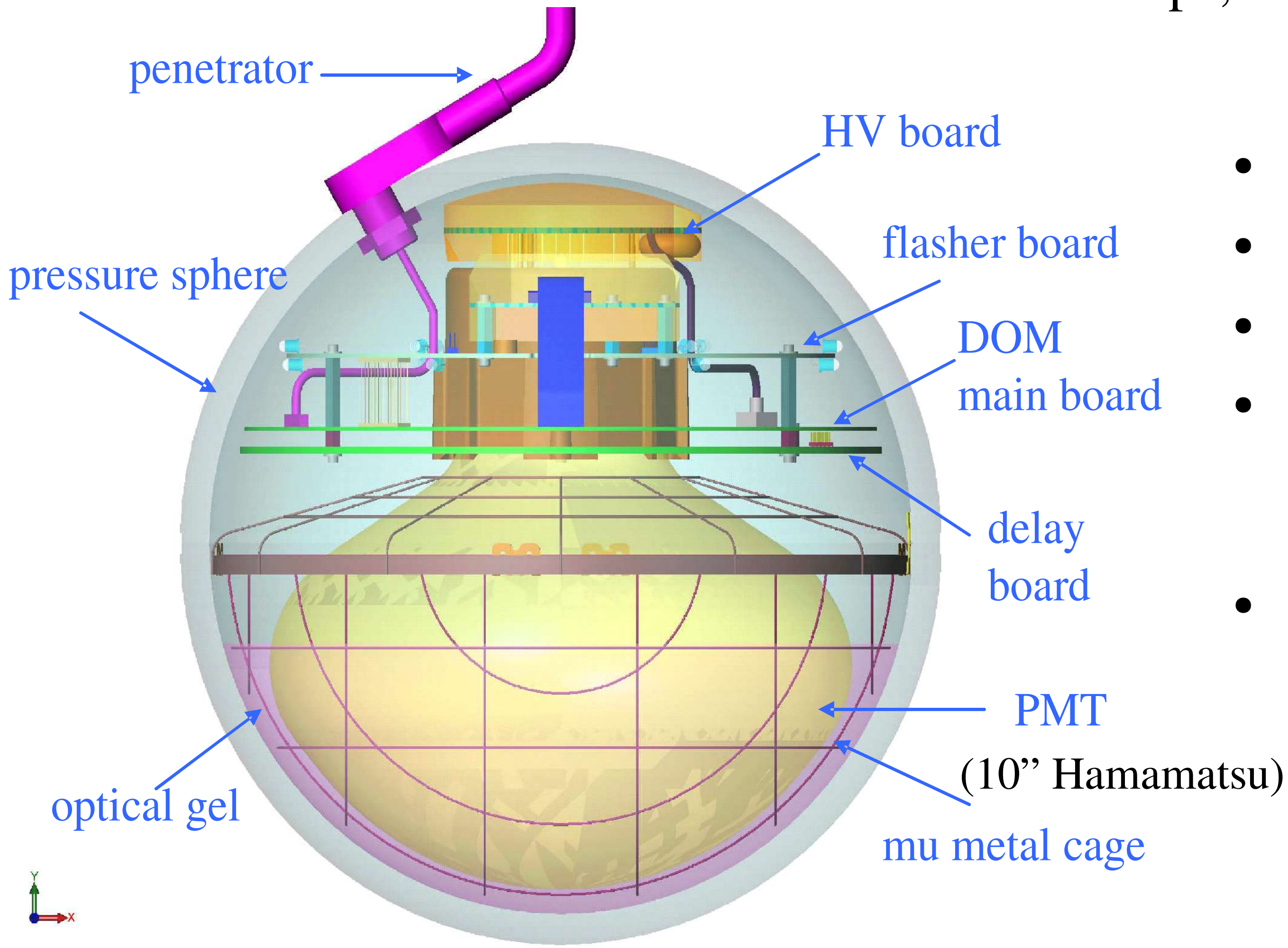
- Ice volume: 1 km3 (~Giga ton ice)
  -- 80 strings
  -- 60 DOMs (Digital Optical Moduels) per string
- optimized for TeV-PeV (EeV) ν
  -- 125 m distance between strings
  -- 17 m apart vertically between DOMs
- E_μ threshold: ~100GeV (horizontal)
  ~ 50 GeV (vertical)
- IceTop air shower array:
  -- 160 tanks, 2 DOMs / tank
  -- muon veto, calibration
  -- cosmic ray composition study

Total cost of IceCube: ~$272M

IceCube Detector --cont.

DOM (Digital Optical Module): basic element of the detector

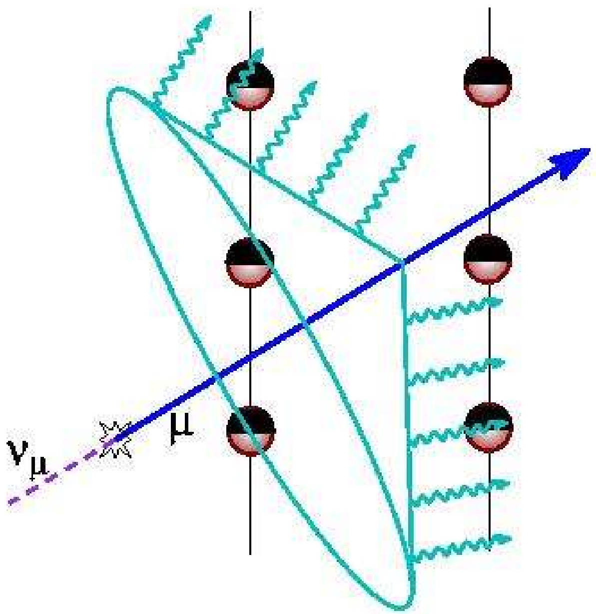
timestamps, digitize waveforms in situ

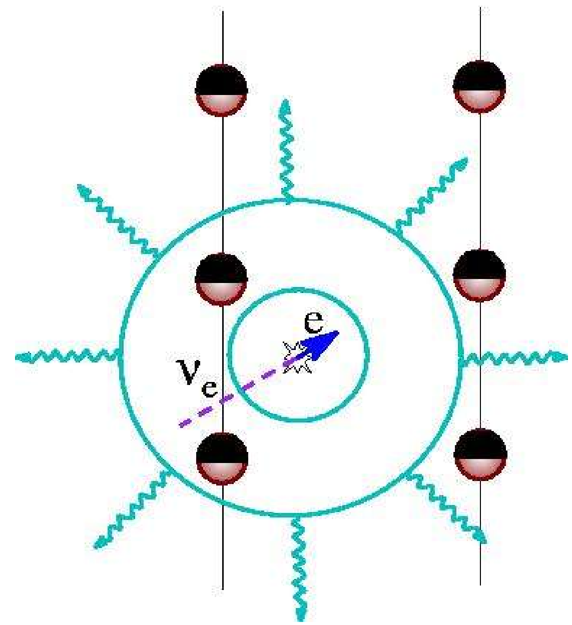


- Noise rate *in situ:* ~1 kHz
- Deadtime < 1%
- Time resolution: < 5 ns
- Dynamic range:
  - 200 photoelectrons / 15 ns
  - 2000 PE integrated / 5 μs
- Digitization rate:
  - 300 MHz for first ~400 ns (128 samples, 3ns/sample)
  - 40 MHz for 6.4 μs (256 samples, 25ns/sample)

IceCube Detector --cont.

Neutrino detection: collection of Cherenkov lights due to mu,e,tau produced by neutrinos





ν_μ : CC interaction

$$\theta_c = \cos^{-1}\left(\frac{1}{\beta n}\right) \approx 41^0$$ (in water/ice)

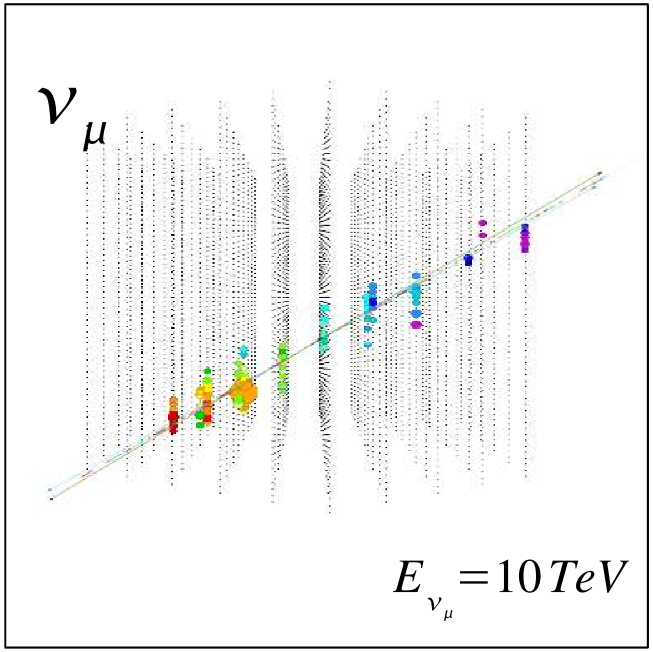
shower (cascade)

ν_e : CC, NC interactions

ν_τ : CC interaction ν_μ: NC interaction

IceCube Detector --cont.

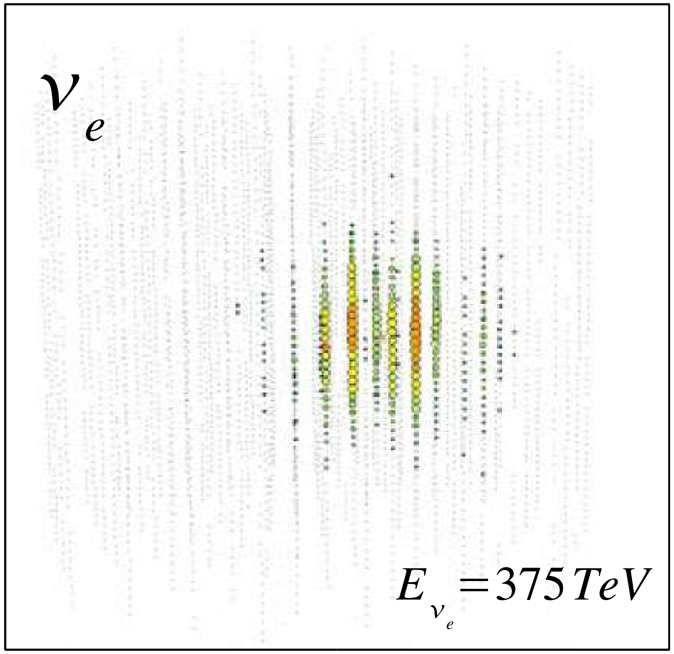
All flavors of neutrino detection:



(10TeV muon travel ~2km)

E resolution: ~30% log(E/GeV)

angular resolution: < 1 deg

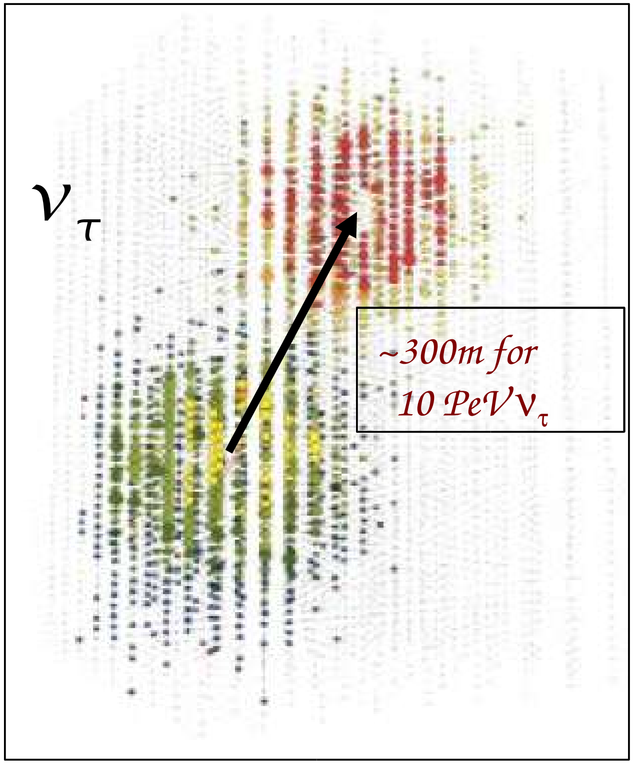


(1PeV cascade: R ~ 250m)

E resolution: ~10% log(E/GeV)

$$e.g.,\ E_\nu = 1\,TeV^{+1\,TeV}_{-0.5\,TeV}$$

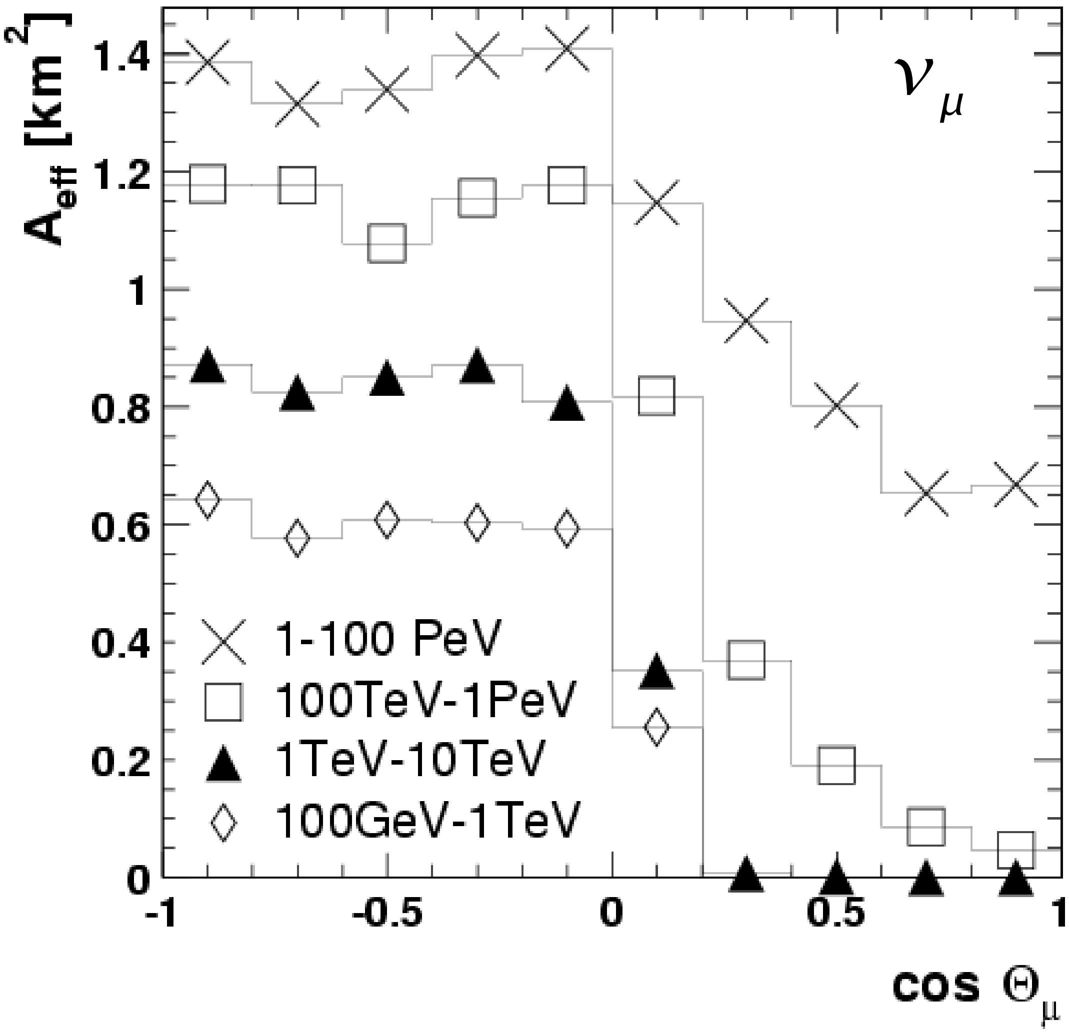
angular resolution: ~27 deg



double bang,
lolli pop

IceCube Detector --cont.

Effective detector area <--- measure of detector efficiency



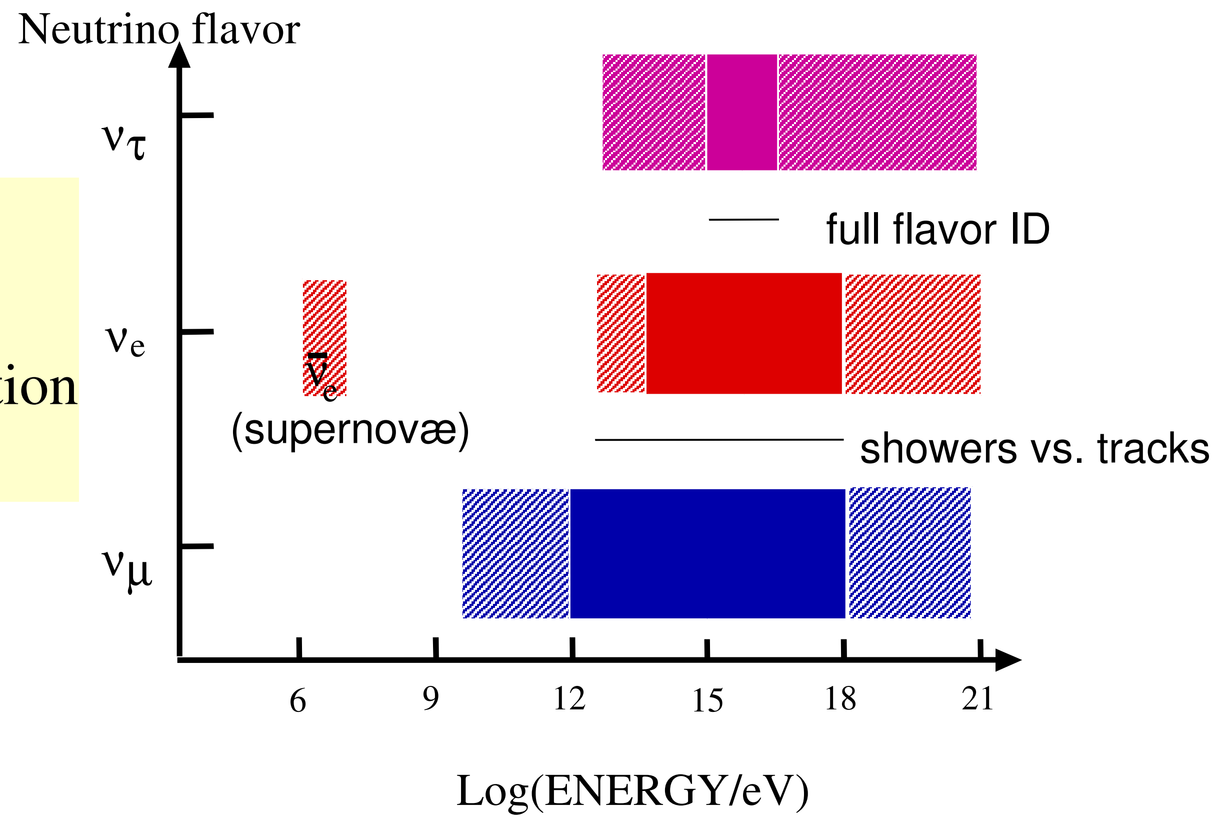
$$A_{eff}(E_\nu,\theta_\nu;flavor)=\frac{N_{detected}(E_\nu,\theta_\nu;flavor)}{N_{generated}(E_\nu,\theta_\nu:flavor)}\times A_{gen}$$

Higher energy, more efficient!

IceCube Detector --cont.

Neutrino flavor vs. Energy

These are conservative because AMANDA MC software and reconstruction techniques are used.

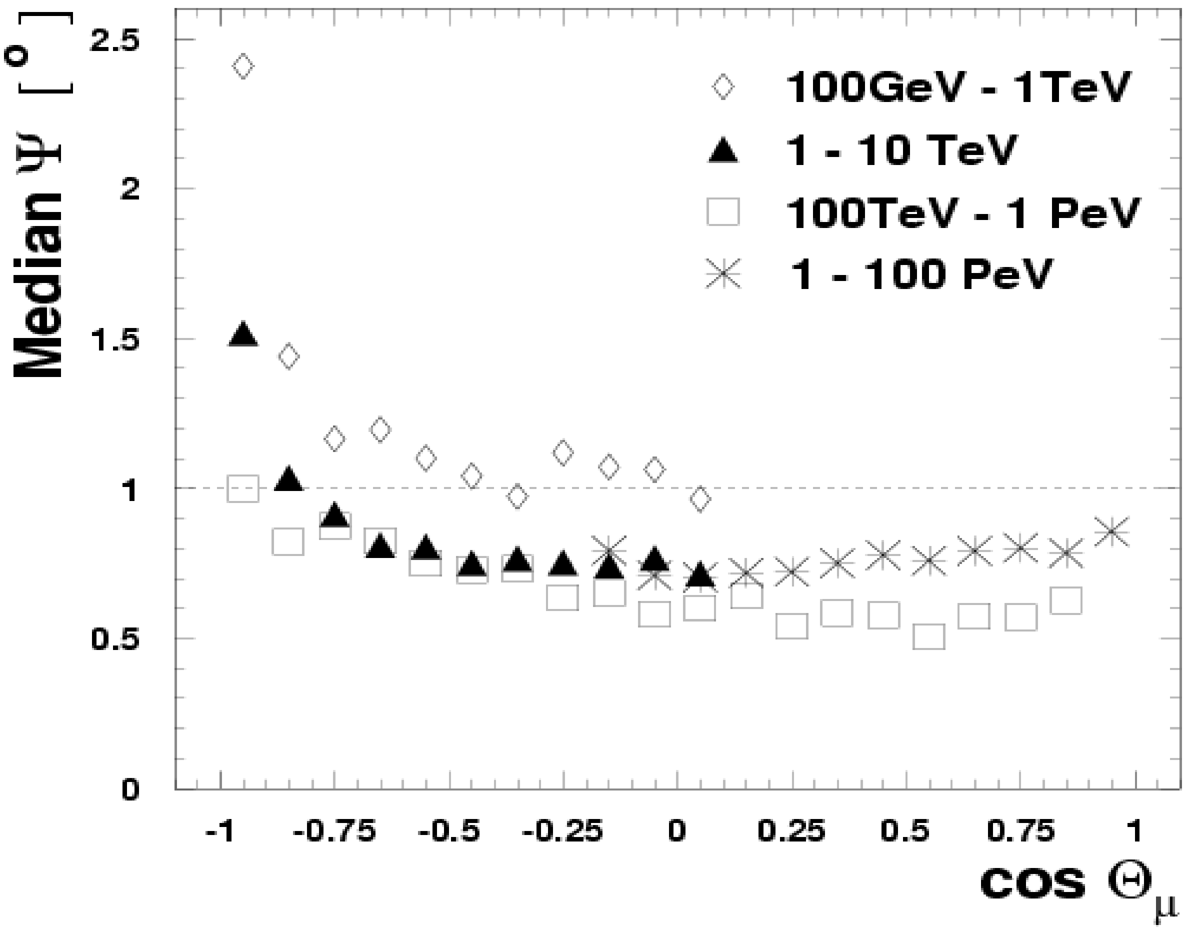


-- Solid areas: best reconstruction (flavor, direction, energy)

-- Hatched areas: difficult reconstruction (triggers).

IceCube Detector --cont.

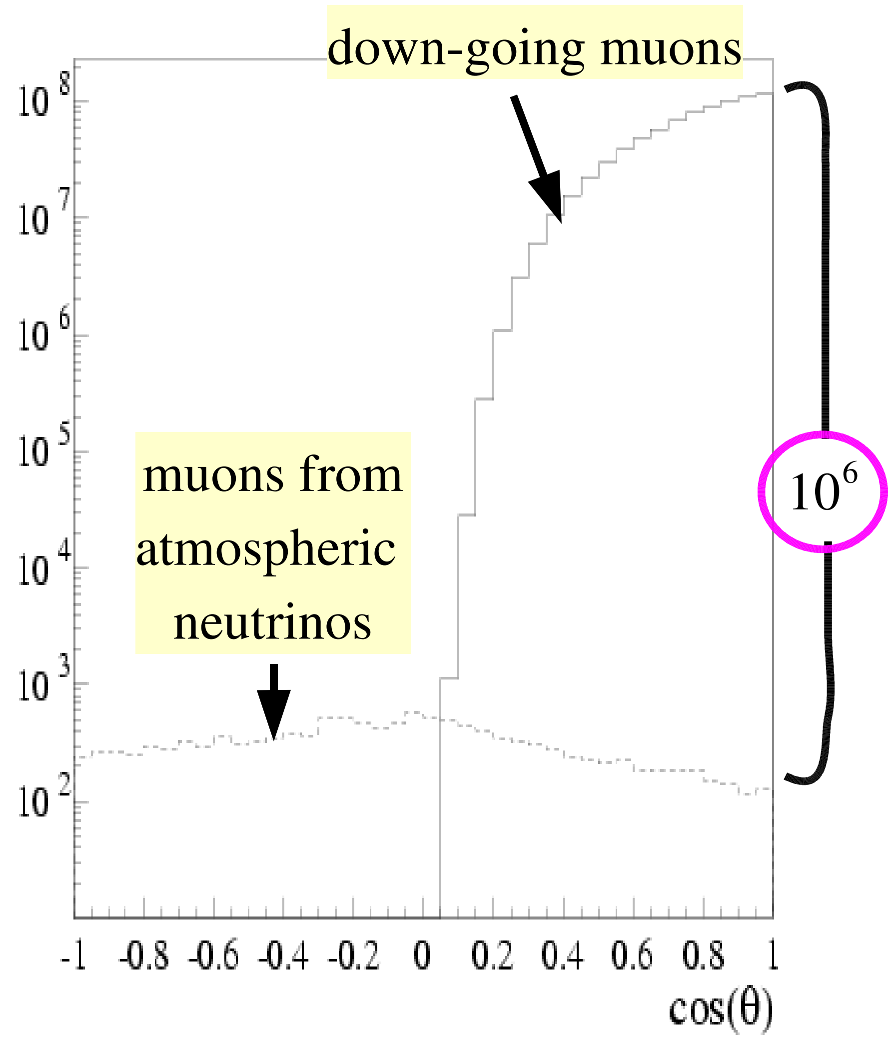
Angular resolution



IceCube Detector --cont.

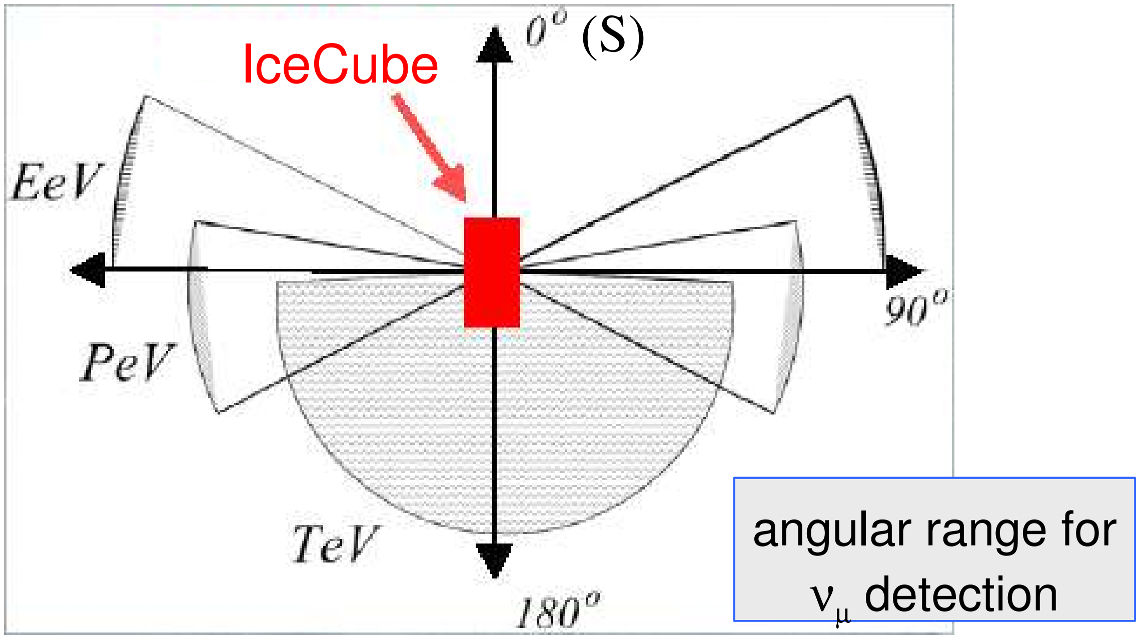
Background:

- BG of muon channel:
  - -- up-going atmospheric ν_μ induced muon
  - -- mis-reconstructed down-going muon
- BG of cascade channel:
  - -- About an order of magnitude lower than that of muon channel.
  - -- prompt charmed meson decay --> ν_τ (Dominant source of BG at E > 100TeV. However, exact amount is poorly known, thus it's hard to get rid of this BG.)



IceCube Detector --cont.

Limited muon field of view: to minimize BG



- TeV: look down to avoid atmos. muons
- PeV: Earth opaque, look horizontally
- EeV: Can look above horizon – atmospherics are at lower energy

cf. cascades: 4π, except for absorption at high energies (with muons vetoed!)

Science Goals

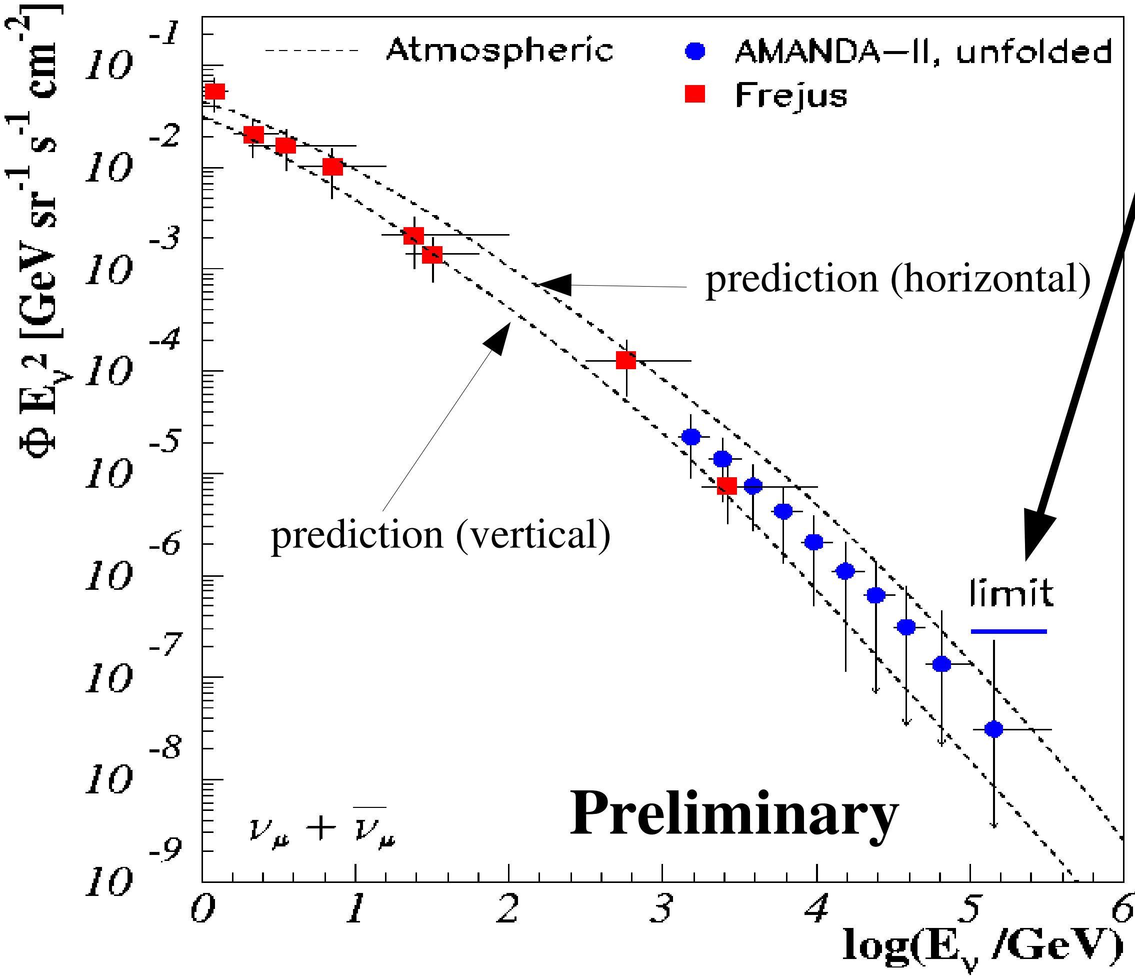
Outline

- Search for extraterrestrial sources of neutrinos
  --- point source: AGN, GRB, SNR etc...
  --- diffuse flux
- **Indirect WIMP search** (~TeV mass range)
- Atmospheric neutrino spectrum
- UHE/EHE neutrinos (GZK ν)
- Cosmic ray: composition (above knee), E spectrum
- Monitoring galactic SN
- Monopole search
- Extraterrestrial neutrino oscillation (megaparsec baseline)
- TeV-scale extra dimensions, electroweak instantons,…

** Most of the cases in following slides I'll show AMANDA results to compare w/ IceCube sensitivity.

AMANDA Results/IceCube Sensitivity

Atmospheric $\nu_u + \bar{\nu}_u$ **:** mainly for detector verification and calibration.



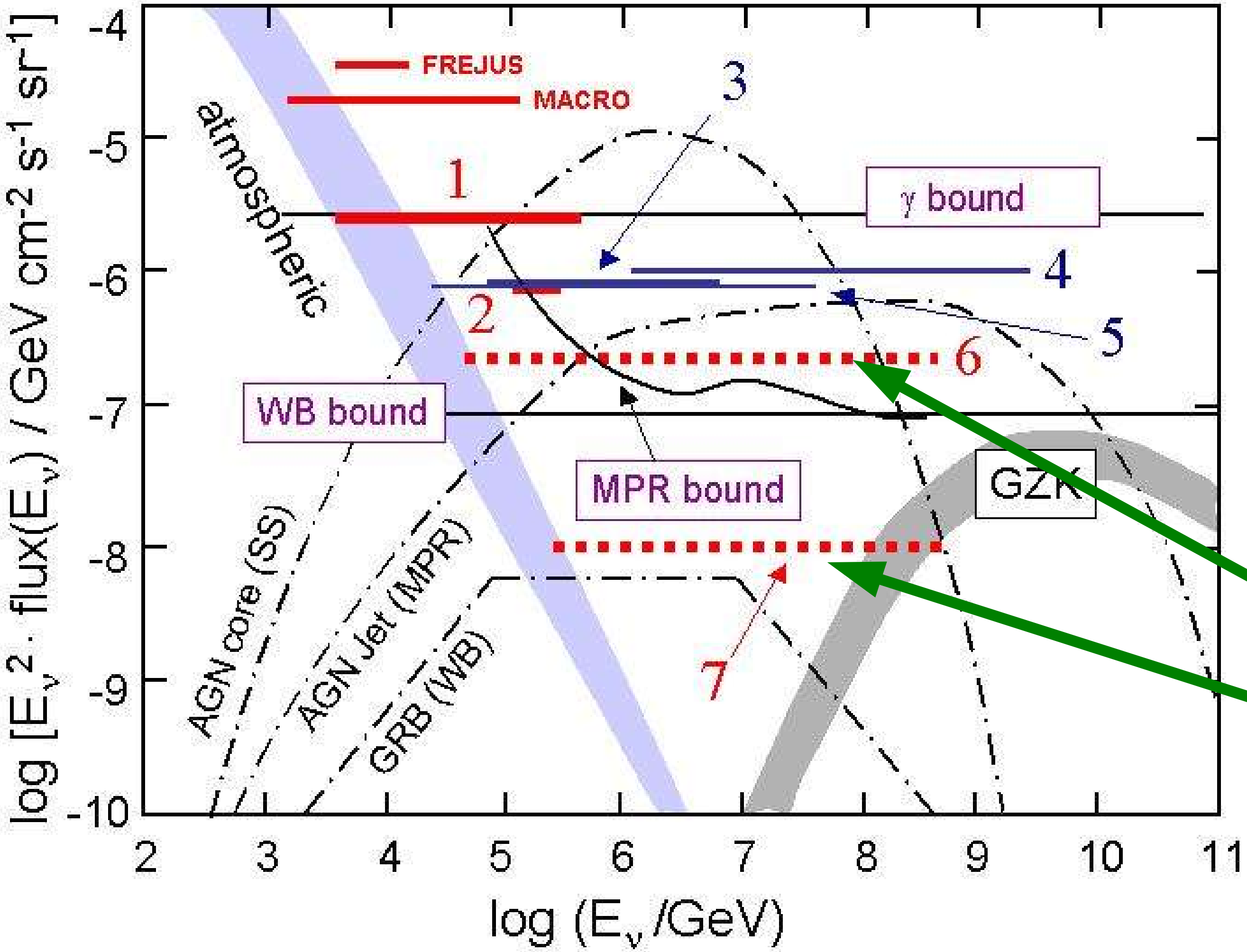
Also can set preliminary upper limit on the diffuse flux in the highest E bin (100TeV ~ 300TeV).

$$\Phi E_\nu^2 < 2.6 \times 10^{-7} GeV\ sr^{-1} cm^{-2}$$

- AMANDA data (1TeV-300TeV) matches well w/ low E Frejus data.
- IceCube data will reduce statistical, systematical errors. (W/ much higher statistics, IceCube might study atm nu osciallation.)

AMANDA Results/IceCube Sensitivity --cont.

Diffuse flux: --> no directional info. --> muon, cascade channels



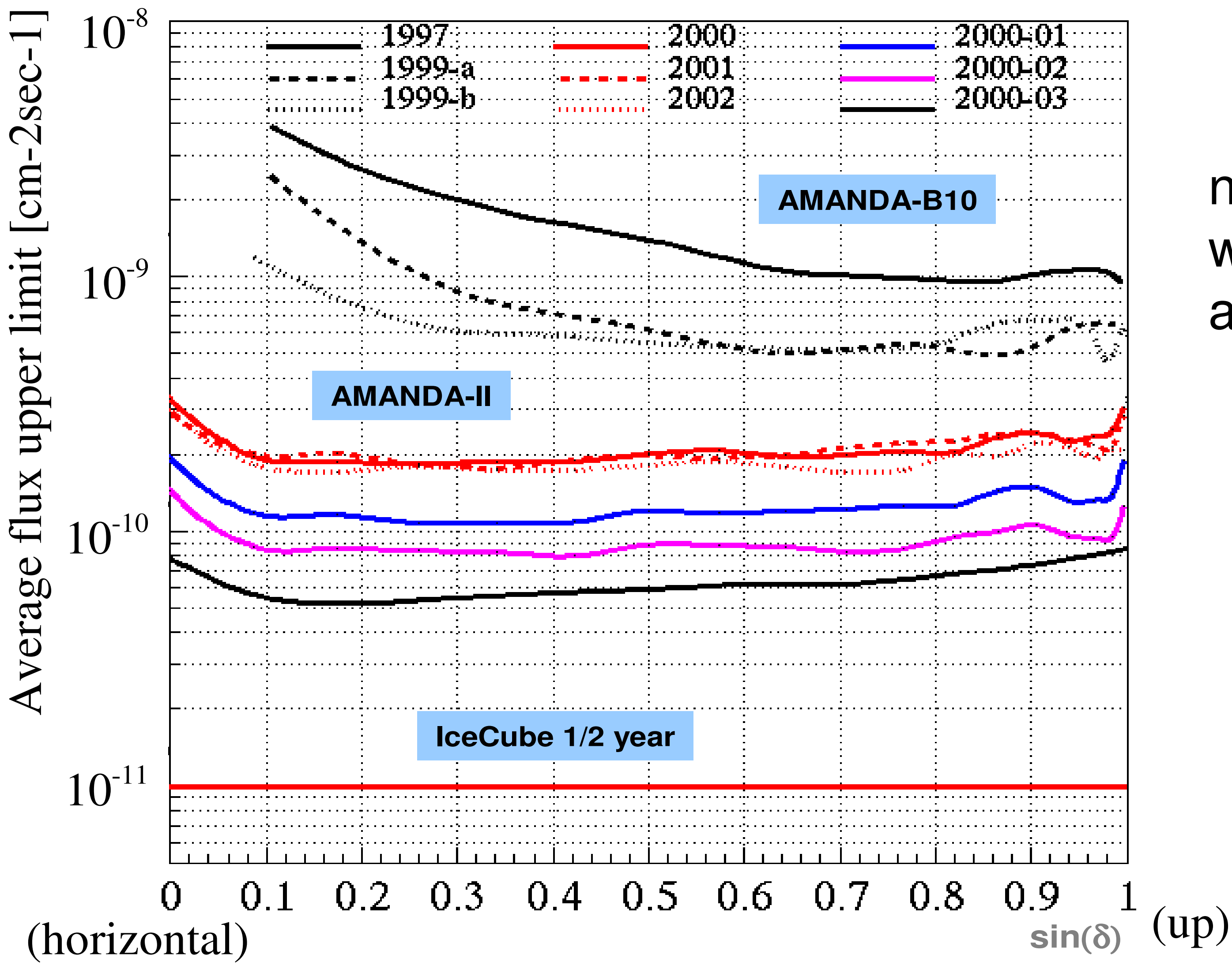
1. AMANDA B-10 (Y1997)
2. AMANDA Y2000 (from Atmos. nu)
3. AMANDA Y2000 (from cascade channel)
4. AMANDA (Y1997) (from UHE events)
5. Baikal (1998-2003) (from cascade channel)
6. AMANDA (4 yrs of data)
7. IceCube (w/ 3yrs of data)

AMANDA Results/IceCube Sensitivity --cont.

Date	New Strings added	Accumulated string-yrs/yr	total accumulated string-yrs	total accumulated km3-yrs	diffuse UHE muons @1e-7	diffuse UHE cascades @1e-7
Feb-05	1	0	0			
Feb-06	10	1	1			
Feb-07	16	11	12	0.15	8	4
Feb-08	18	27	39	0.49	24	13

AMANDA Results/IceCube Sensitivity --cont.

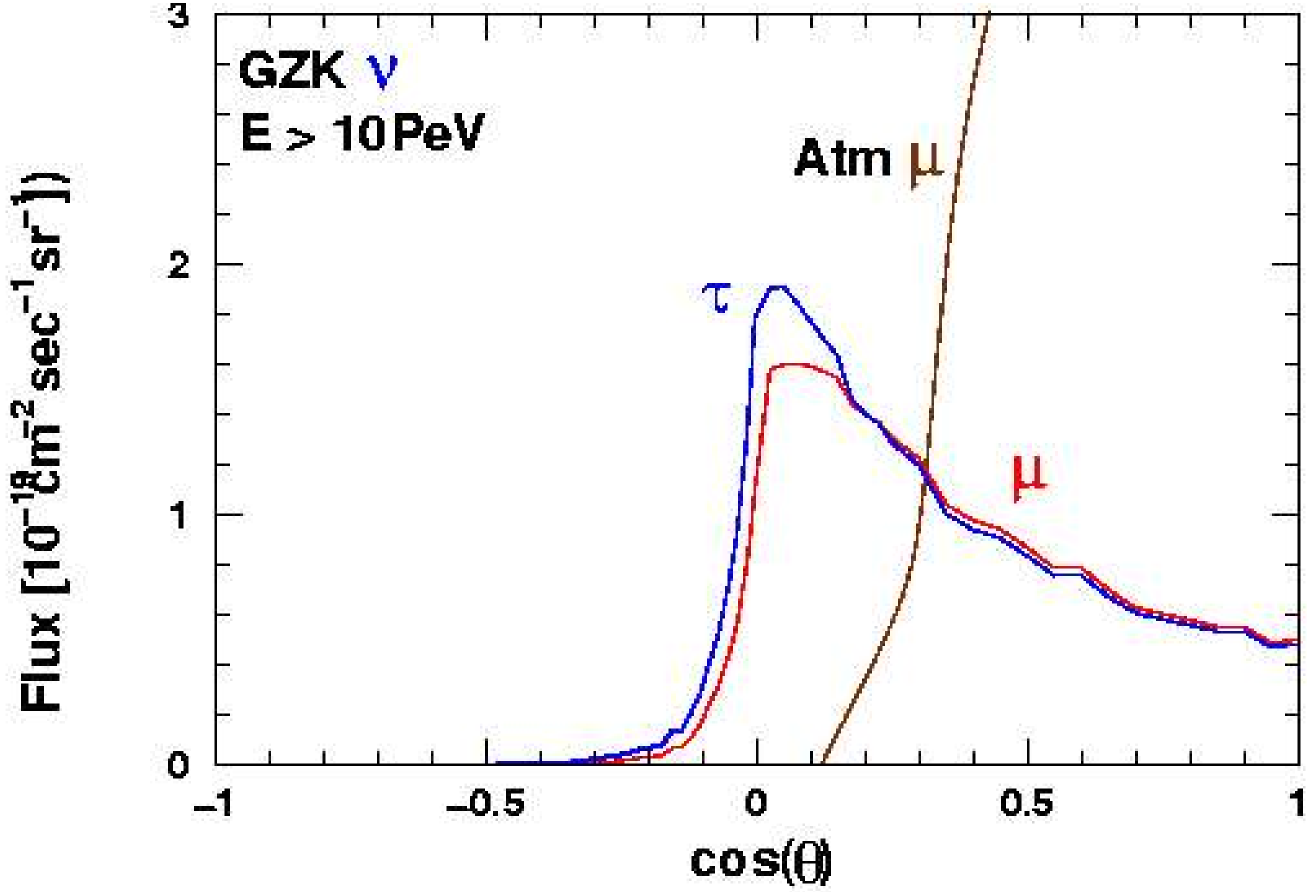
Point source: good pointing resolution is required. $\rightarrow \nu_\mu + \bar{\nu}_\mu$ (TeV~PeV)



note: E^{-2} spectrum was integrated above 1 TeV.

AMANDA Results/IceCube Sensitivity --cont.

EHE ν : produced by EHE CR interaction w/ CMB
(a.k.a. GZK ν): 0.1EeV ~ 100 EeV



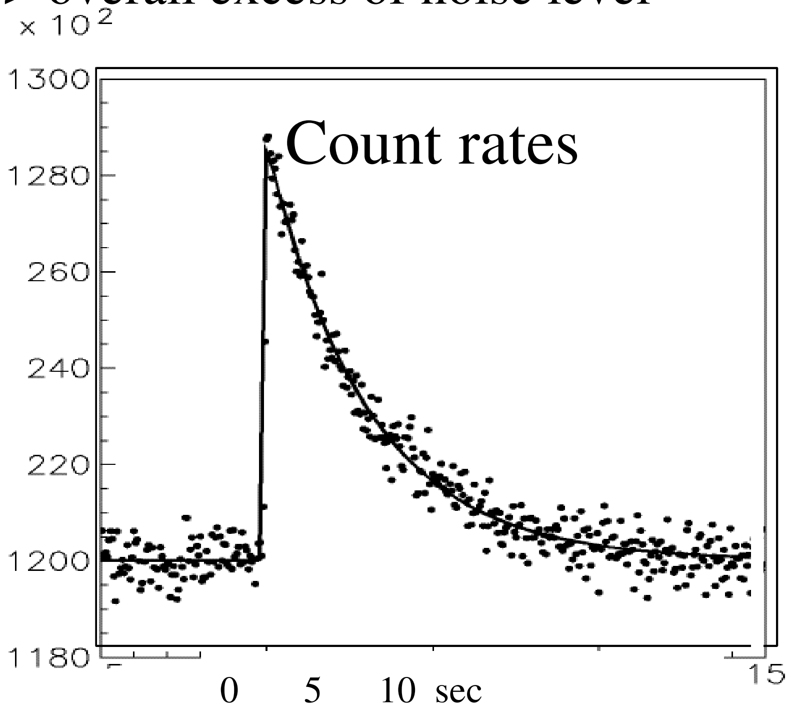
AMANDA Results/IceCube Sensitivity --cont.

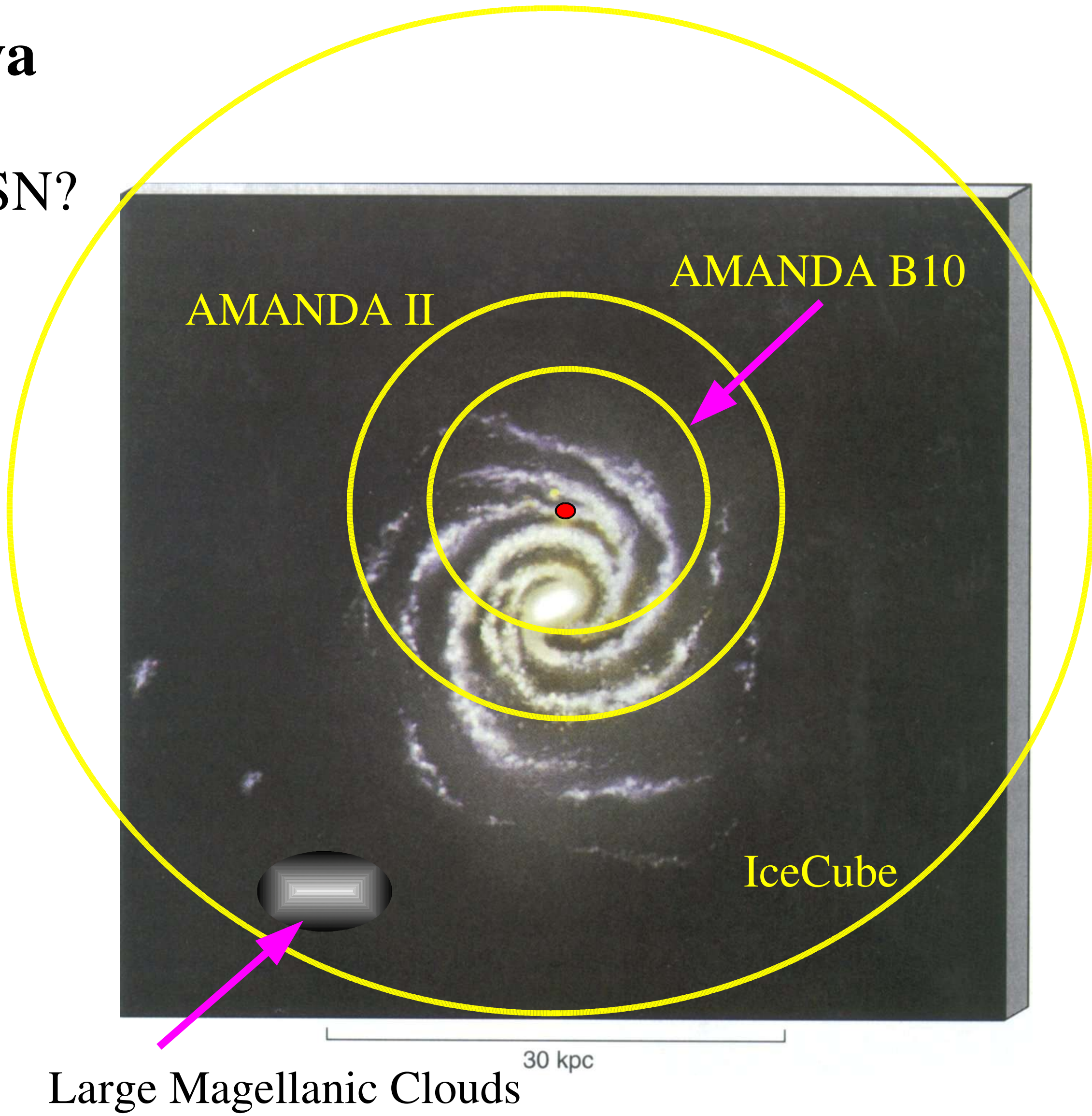
Monitoring Galactic Super Nova

How to detect $\bar{\nu}_e$ (~10MeV) from SN?

- IceCube can't be triggered by such low E neutrinos.
- Upon receipt of SNEWS, read out all DOMs for ~10 sec.

--> overall excess of noise level

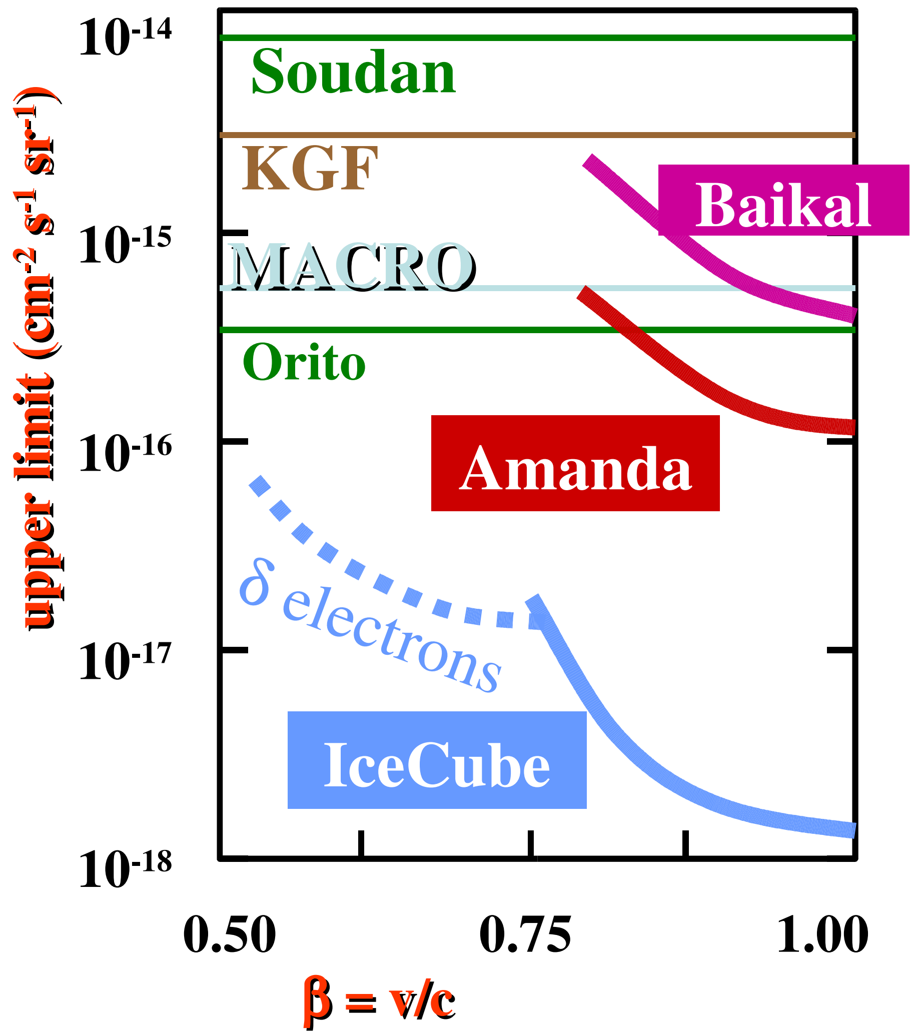




AMANDA Results/IceCube Sensitivity --cont.

Magnetic monopole search

- Relativistic monopoles: Cherenkov emission enhanced by $(g/e)^2 \approx 8300$ compared to muons.
- May be able to look for slow monopoles by detecting δ electrons generated along the path of the monopoles.
- Can also look for nuclearites, Q-balls,…



WIMP Search

Dark Matter (DM):

- DM candidates:
  -- baryonic: MACHOs, cold gas, white dwarf
  -- non-baryonic (23% of universe): WIMPs <-- non-relativistic relic particles
  neutrinos, axions

- Favorite WIMP candidate: lightest neutralino from MSSM

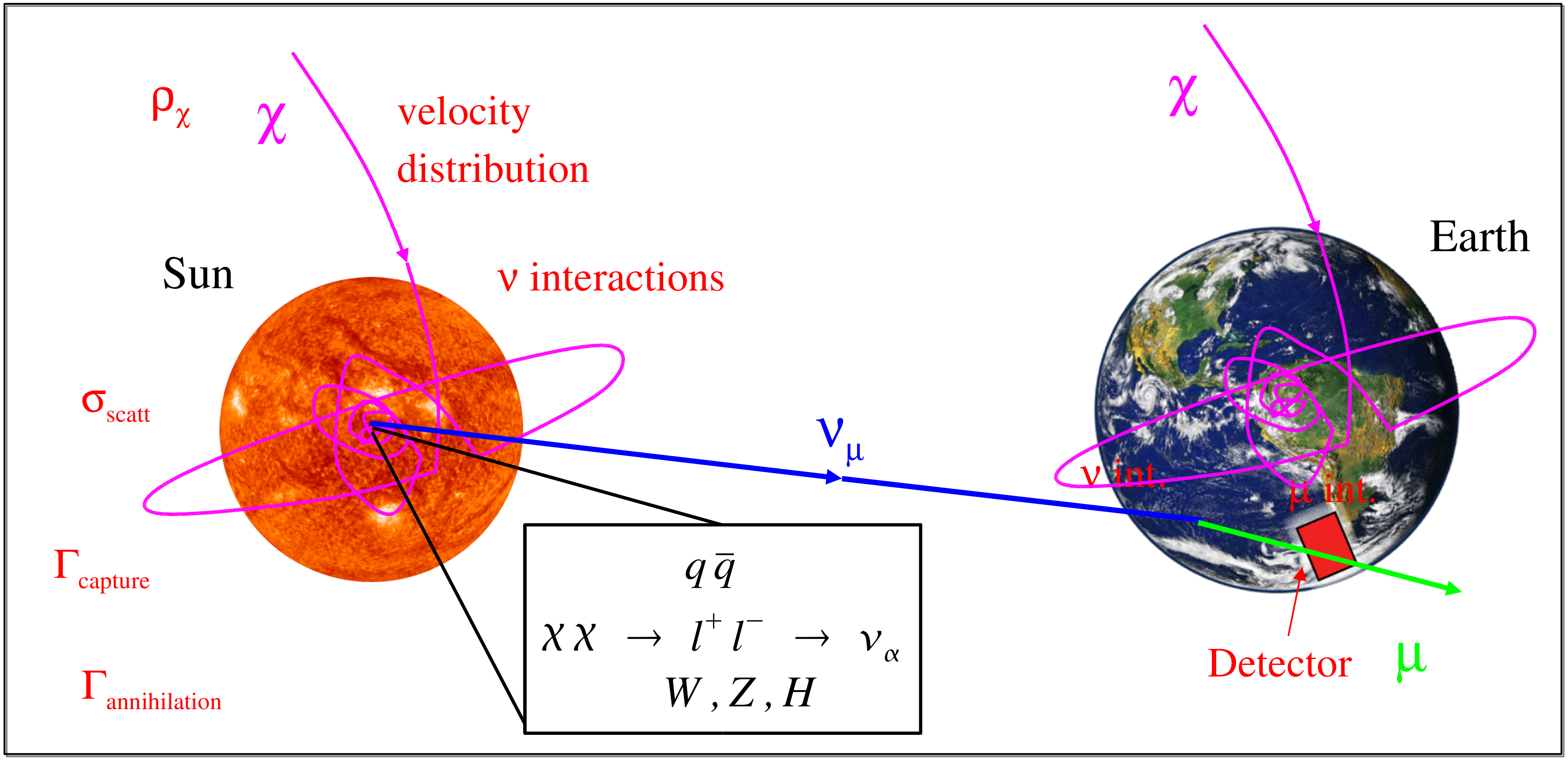
- Neutralino ($\bar{\chi}_1^0$):
  -- linear combination of susy-partners of EW neutral gauge bosons ($\tilde{B}, \tilde{W}_3$)
  and Higgs bosons ($\tilde{H}_1^0, \tilde{H}_2^0$).
  -- stable (if R-parity is conserved.)
  -- annihilate pairwise (Majorana particle)
  -- mass limit: 6 ~ 20 GeV < $M_{\bar{\chi}_1^0}$ < 340 TeV

WIMP Search --cont.

Indirect WIMP search:

-- Technique: neutralinos interact w/ sun or earth --> lose E (via elastic scattering) --> accumulated neutralinos thermalize --> neutralinos annihilation to neutrino

-- Experiments: SuperK, Baikal, AMANDA, IceCube, ANTARES, NESTOR, NEMO, KM3



WIMP Search --cont.

Solar/earth WIMP search:

- looks at muon channel. $\chi\chi \to b\bar{b}$ (soft channel), $\chi\chi \to W^{+}W^{-}$(hard channel)
- E_{μ} (induced from neutralino annihilation) ~ 25% M_{χ}

  --> IceCube/AMANDA are sensitive to M_{χ} > 50 GeV.

- AMANDA Signal MC:

  -- DARKSUSY (100GeV < M_{χ} < 5000GeV, $90^{0} < \theta < 113^{0}$) <-- solar

  -- DARKSUSY (50GeV < M_{χ} < 5000GeV) <-- earth

- AMANDA BG MC

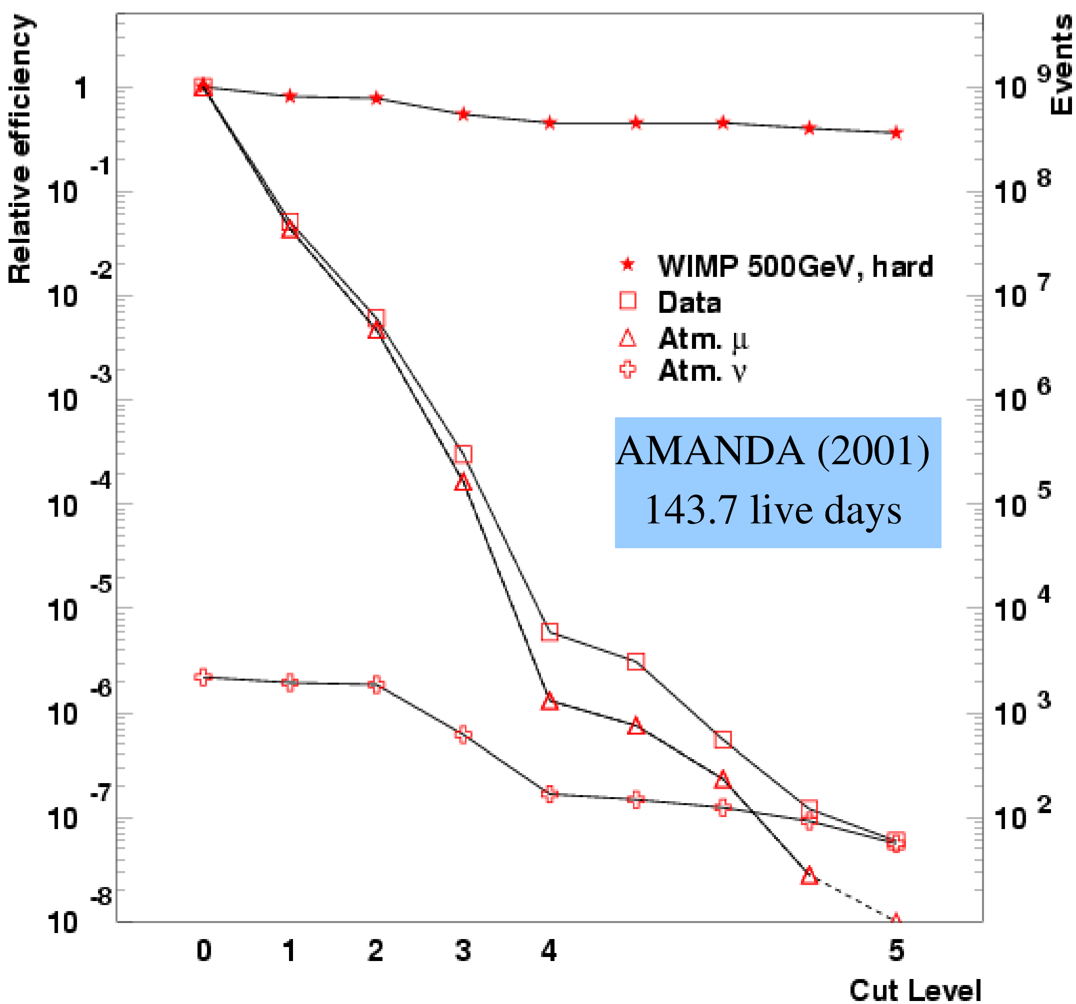
  -- up-going atm. neutrino: ANIS, 10GeV < E_{ν} < 10 PeV, $70^{0} < \theta < 180^{0}$ <-- solar

  NUSIM, 10GeV < E_{ν} <100PeV, $80^{0} < \theta < 180^{0}$ <-- earth

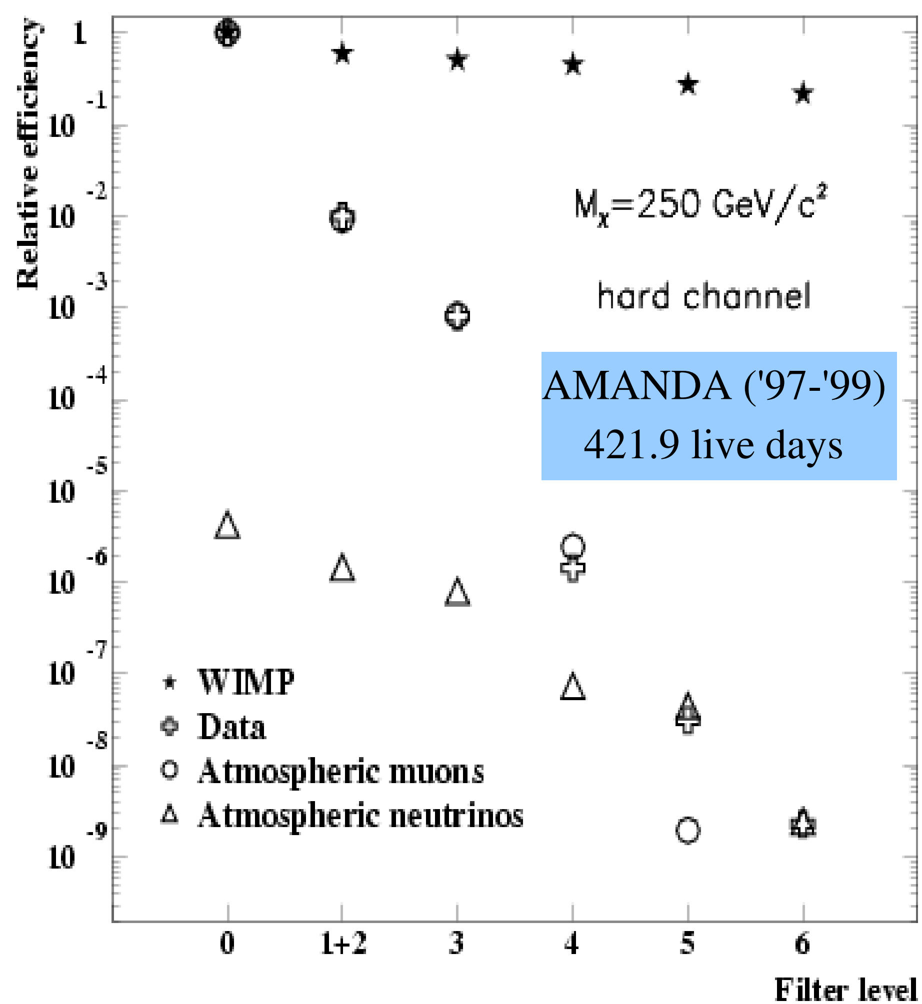
  -- atm. muons : CORSIKA, 600GeV < E_{p} < 10^{11}GeV, $0^{0} < \theta < 85^{0}$

WIMP Search --cont.

Sun



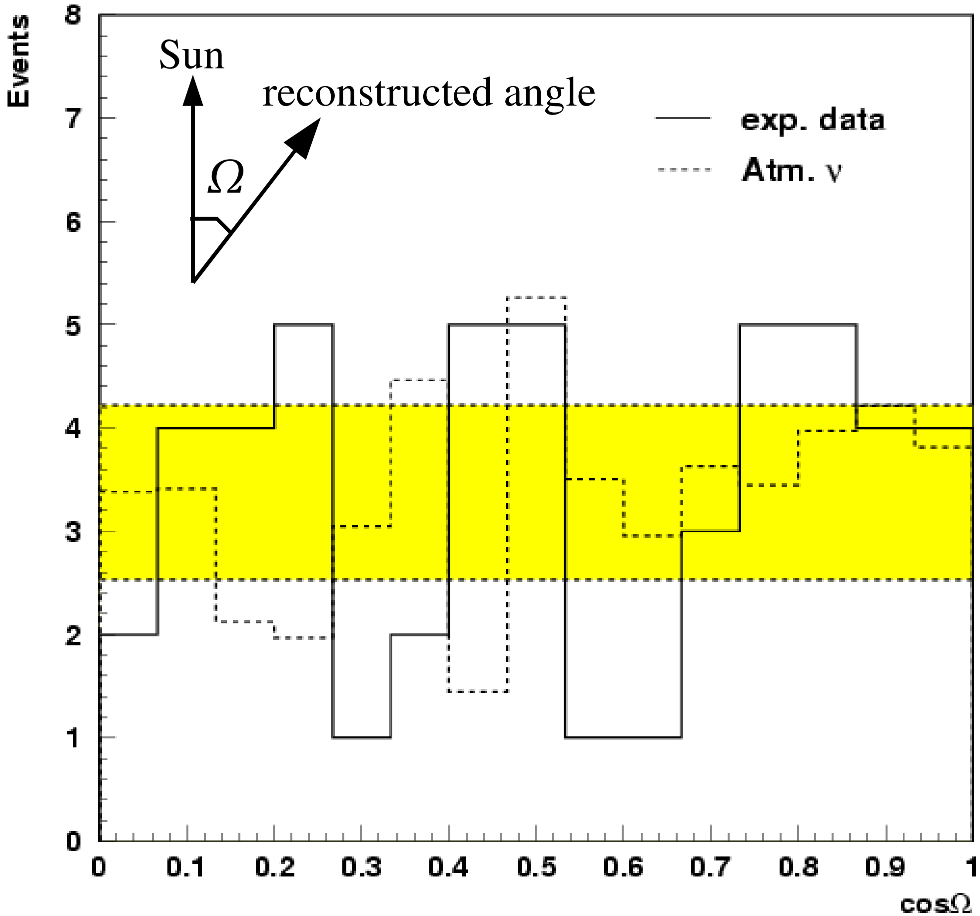
Earth

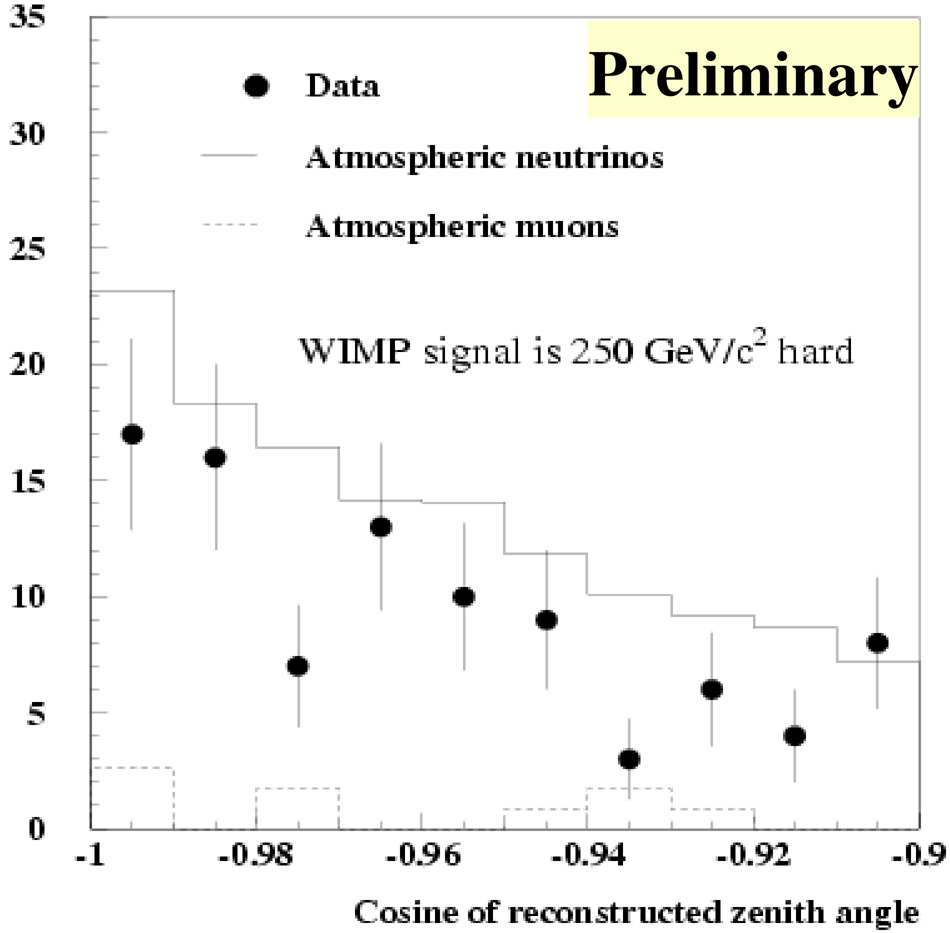


WIMP Search --cont.

Sun AMANDA (2001)
143.7 live days

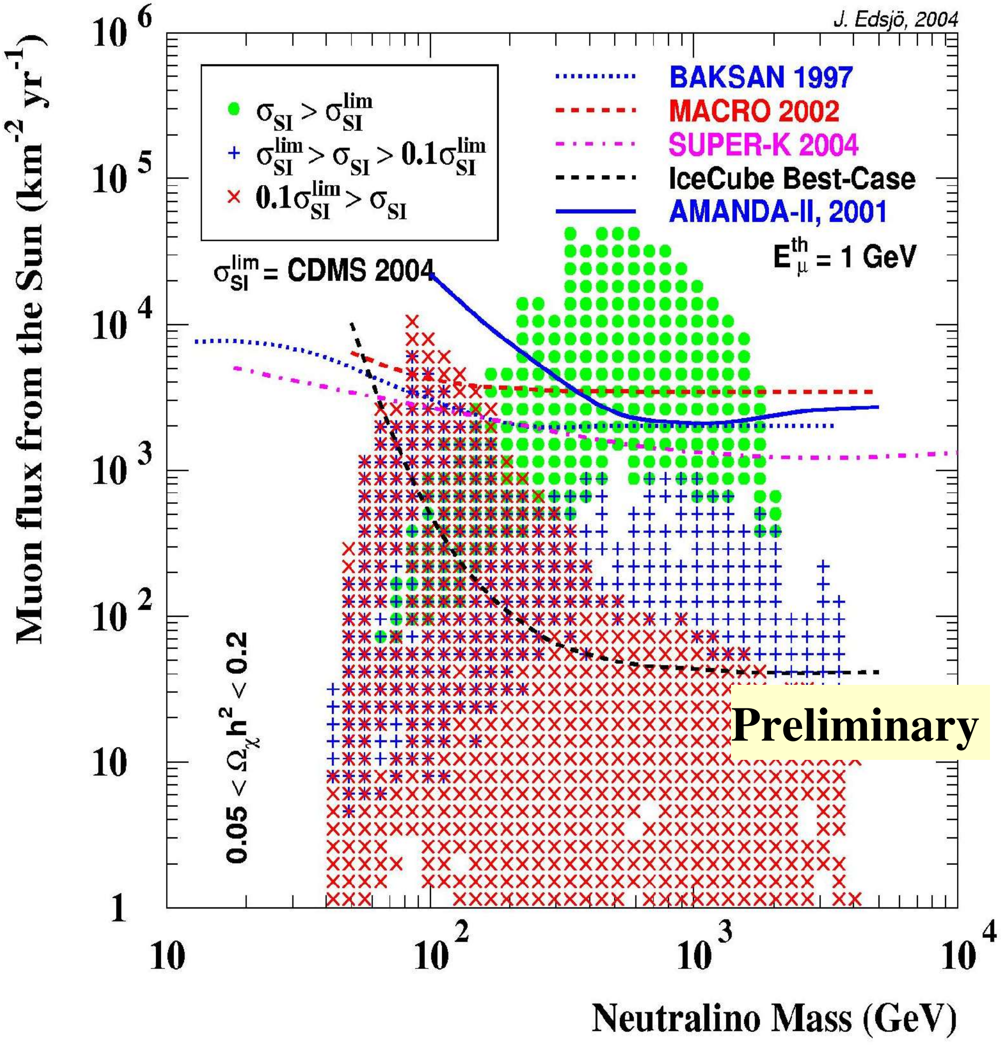
Earth AMANDA ('97-'99)
421.9 live days



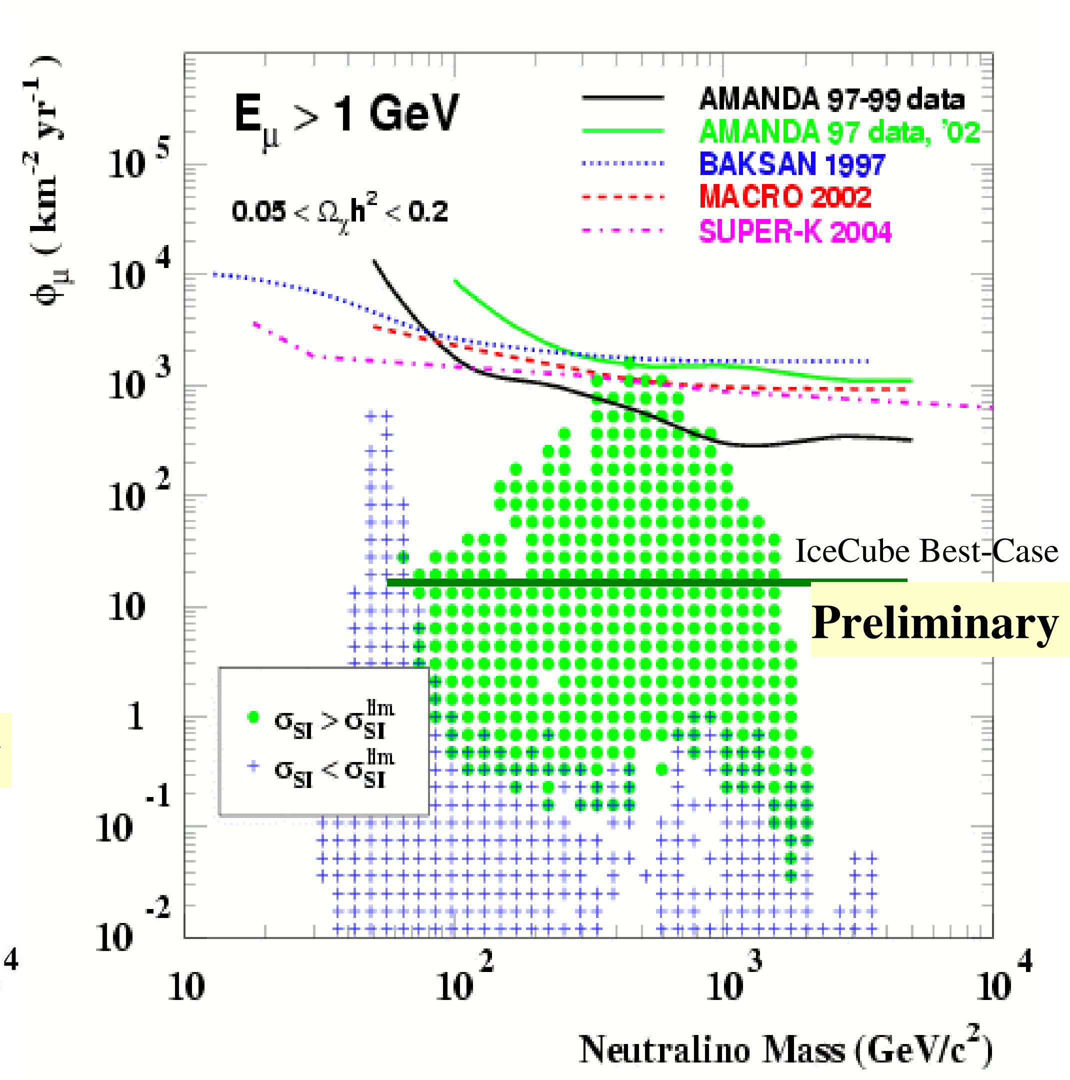


WIMP Search --cont.

Sun

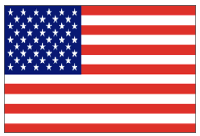


Earth



Current Status

IceCube Collaboration: ~150 members in 26 institutions



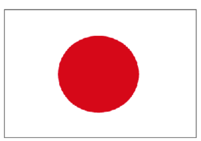
University of Alabama
University of California, Berkeley
Clark-Atlanta University
University of Delaware
Inst. for Advanced Study, Princeton
University of Kansas
Lawrence Berkeley Nat'l Laboratory
University of Maryland
Pennsylvania State University
Southern University and A&M
University of Wisconsin, Madison
University of Wisconsin, River Falls

DESY, Zeuthen
Universität Dortmund
Gutenburg-Universität Mainz
BUGH Wuppertal

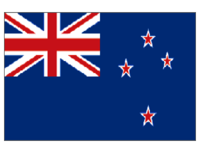
Stockholms Universitet
Uppsala Universitet

Vrije Universiteit Brussel
Université Libre de Bruxelles
Université de Mons-Hainaut

Imperial College, London
University of Oxford



Chiba University



University of Canterbury,
Christchurch

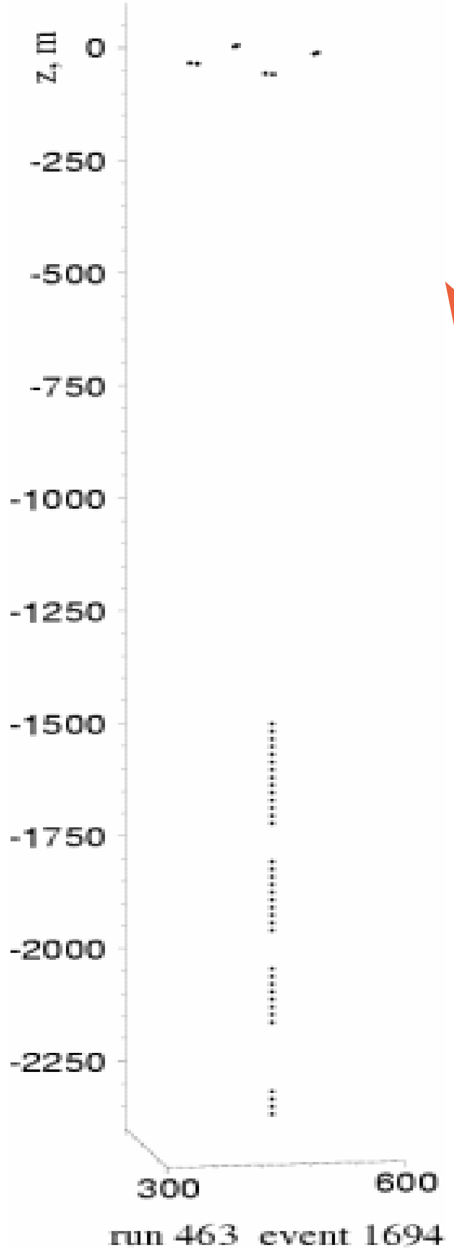
Universiteit Utrecht

AMANDA & IceCube have been officially combined as IceCube since Mar. 2005.

Current Status

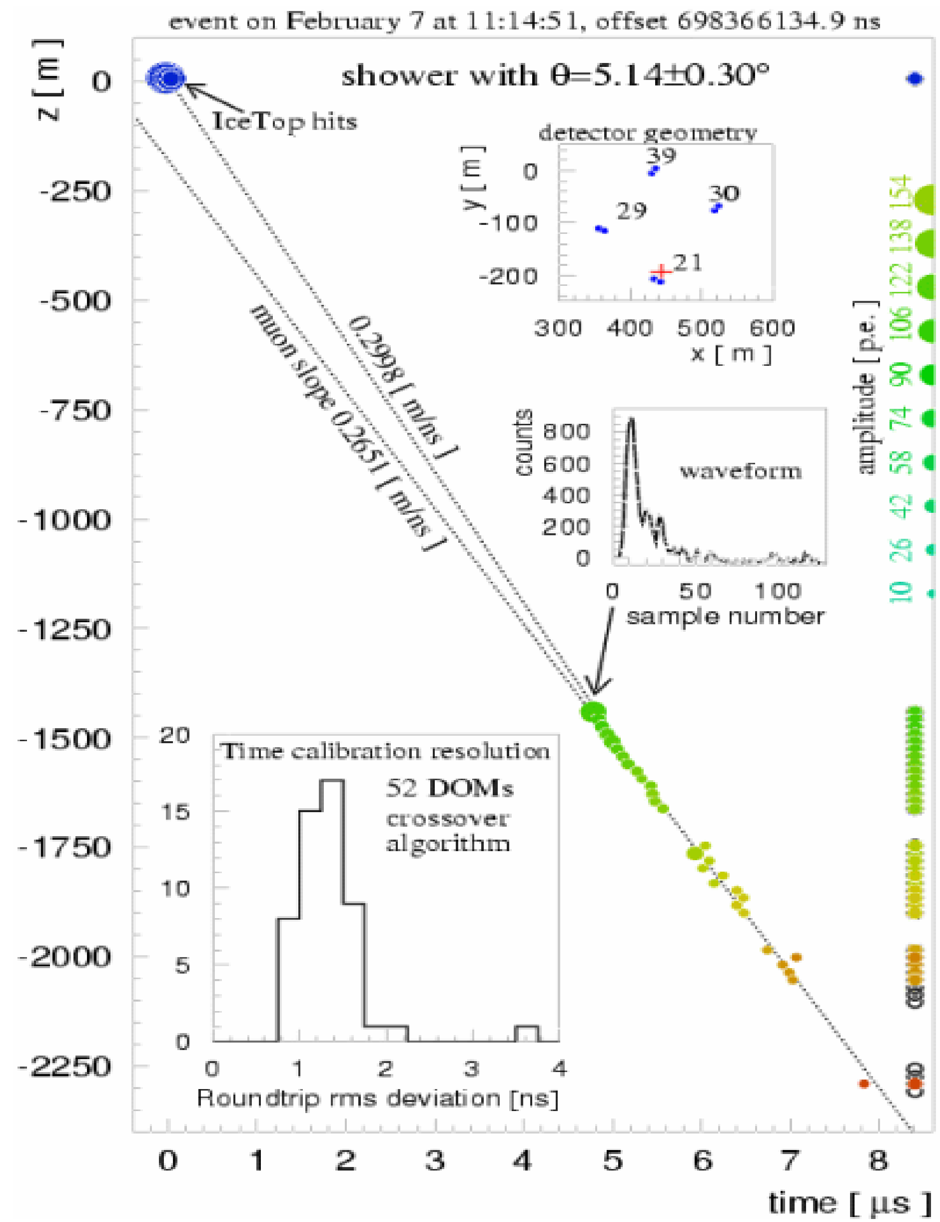
Deployed the first string (string #21) successfully! Jan. 28, 2005

Current Status



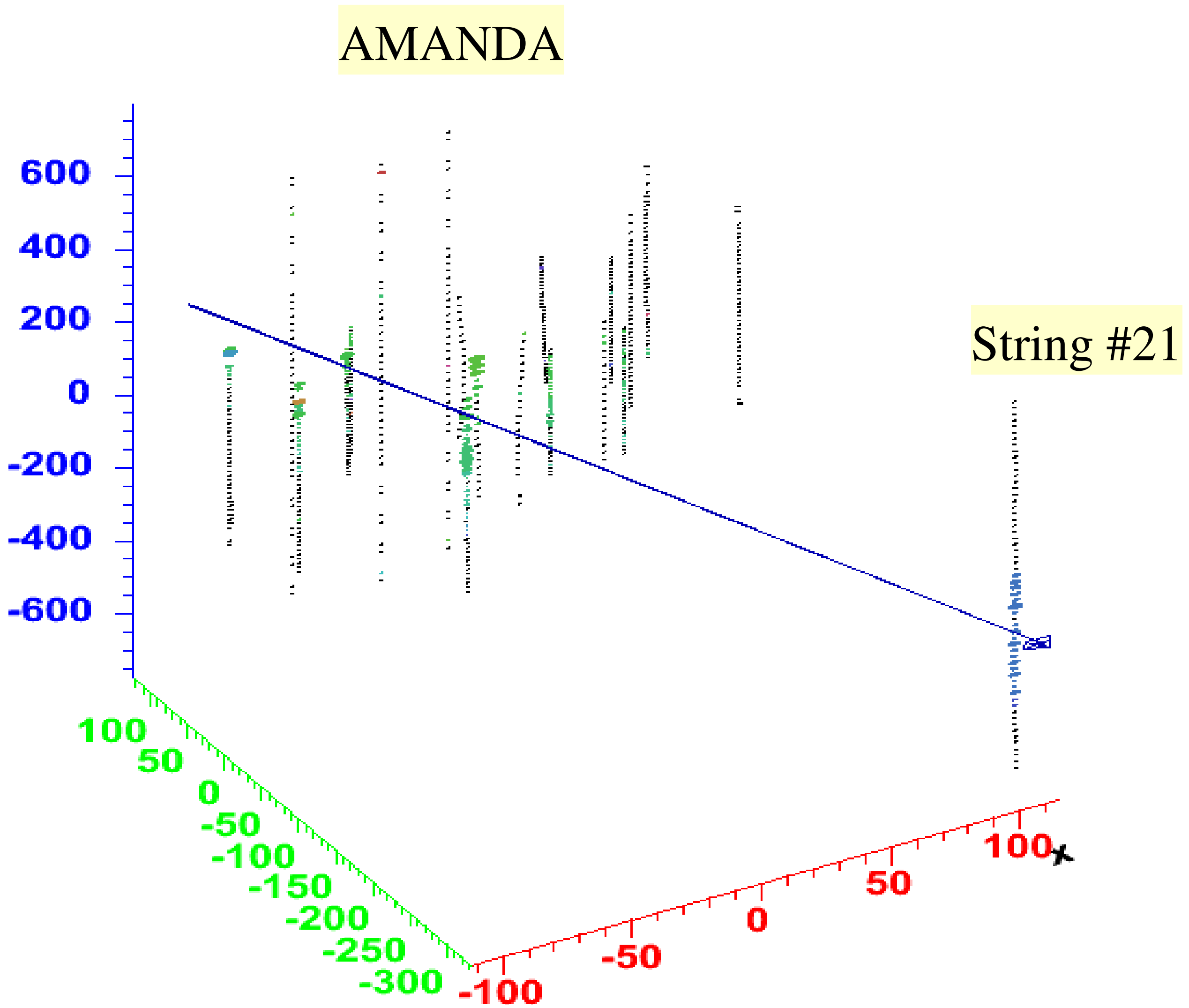
down-going muon event in string #21

4 IceTop tanks are working well!

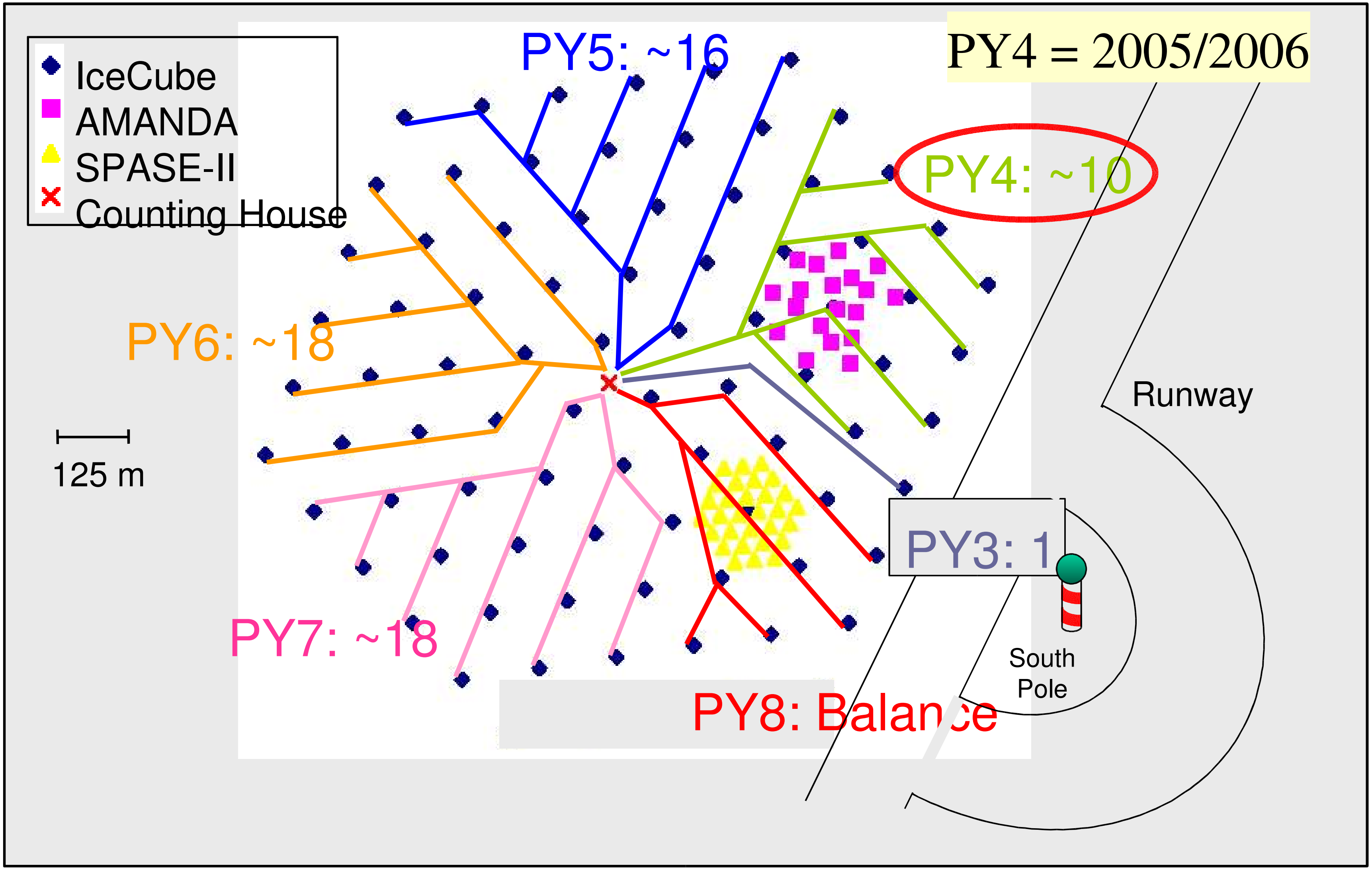


Current Status

AMANDA/IceCube
coincident event

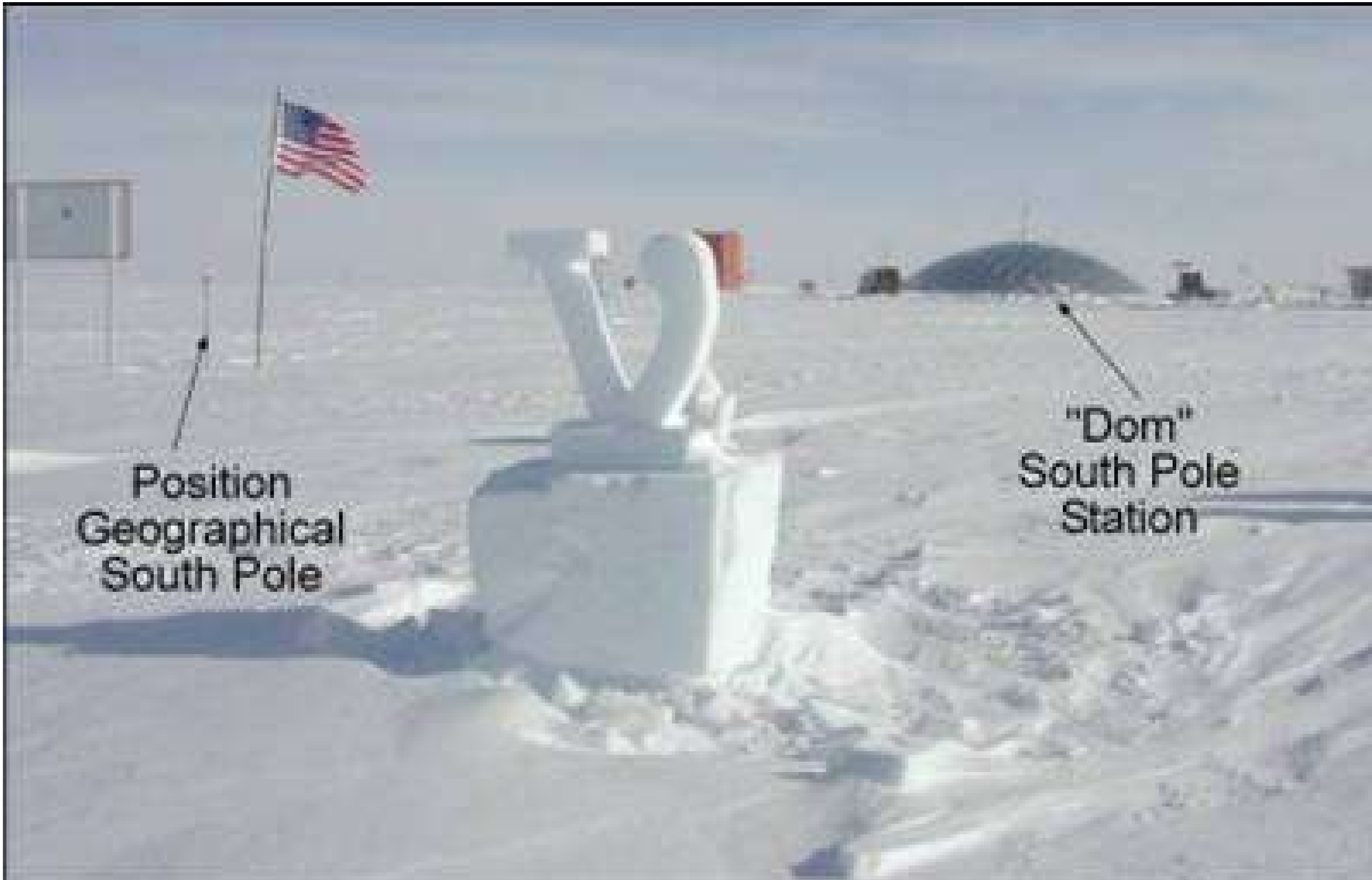


Deployment Schedule



Summary

- IceCube is a neutrino telescope located in deep ice at S. Pole.
- IceCube consists of 4800 DOMs embedded in km3 ice volume.
- IceCube has a great advantage over AMANDA:
  bigger size, higher efficiency, better angular and E resolution etc...
- IceCube has rich science potential.
- Primary goals of IceCube is to find extra terrestrial sources of neutrinos
  (AGN, GRB, SNR, etc...) and WIMP.
- In high solar neutralino mass IceCube will improve current limit
  and complement direct WIMP search exp.
- Other interesting topics: monitoring SN, monopole, cosmic ray etc...
- IceCube deployed its 1st string successfully in Jan. 2005.
- Complete deployment of all 80 strings is planned to be finished by 2010.



Thank you!