IceCube: Status and Prospects

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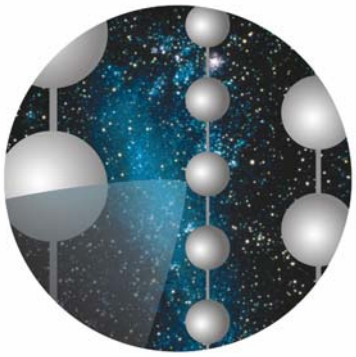

APS Division of Particles and Fields Riverside Meeting

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The IceCube Collaboration

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
Johannes Gutenberg-Universität Mainz
BUGH Wuppertal

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

Stockholms Universitet
Uppsala Universitet

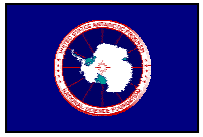
Imperial College, London
University of Oxford

Chiba University

University of Canterbury,
Christchurch

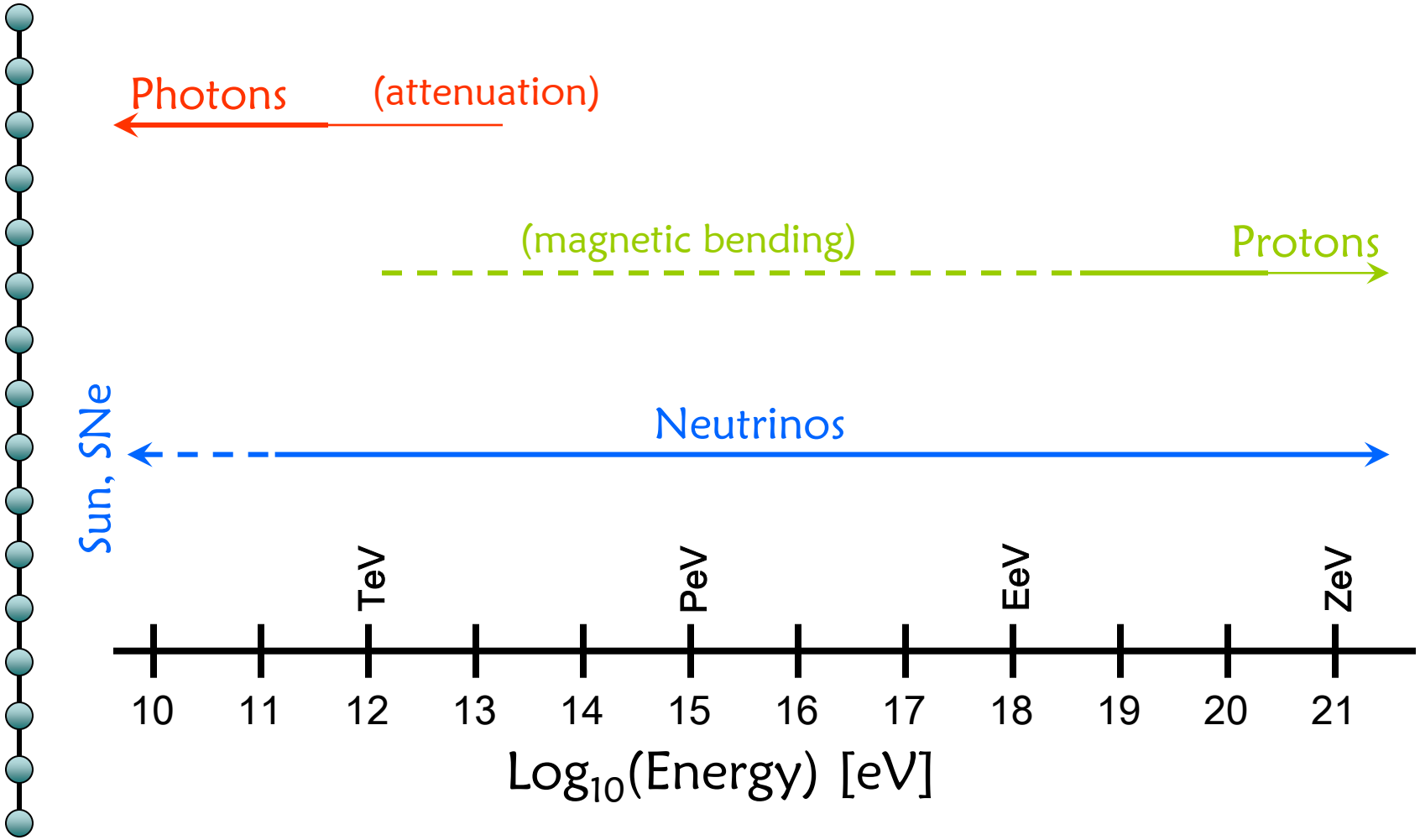
Universiteit Utrecht

Universidad Simón Bolívar,
Caracas



Amundsen-Scott Station,
South Pole

Messenger Particles



Neutrino Production

- Accelerate a hadron beam into a target, just like in a particle accelerator:

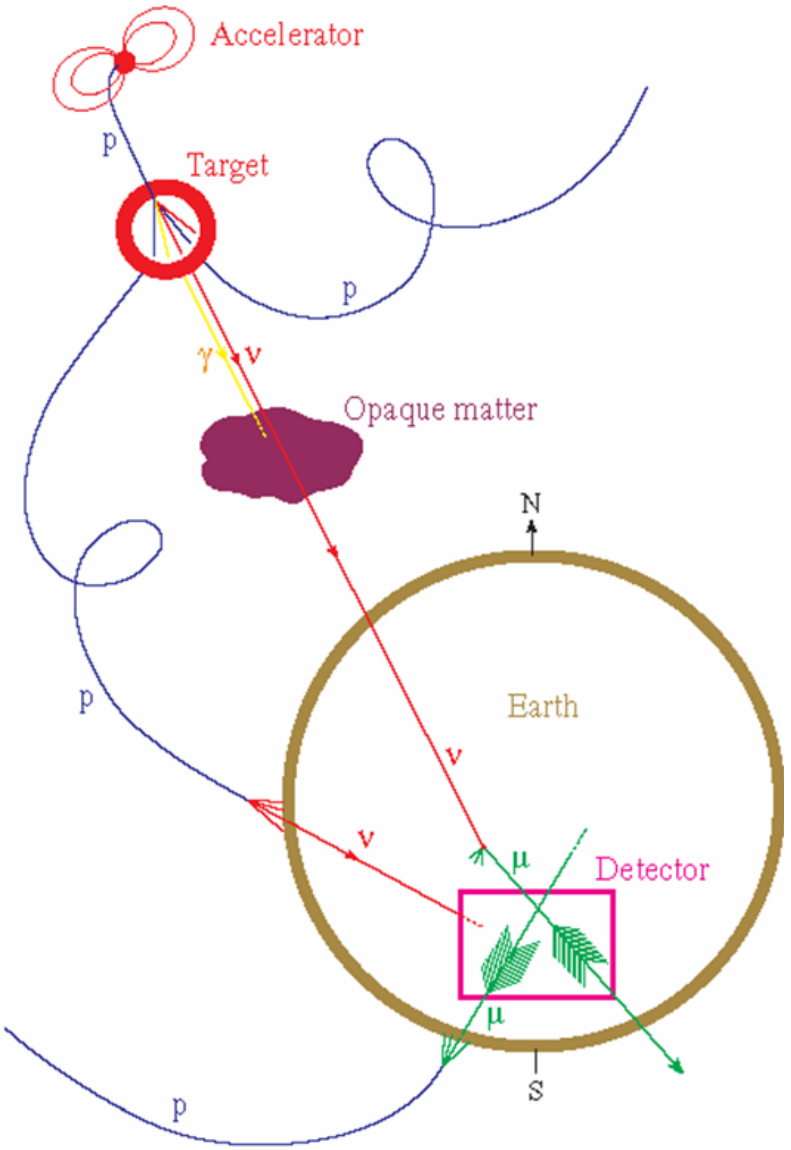
  $p + (p,\gamma) \rightarrow \pi^{\pm} \rightarrow \nu_e, \nu_\mu$

- Also produce photons

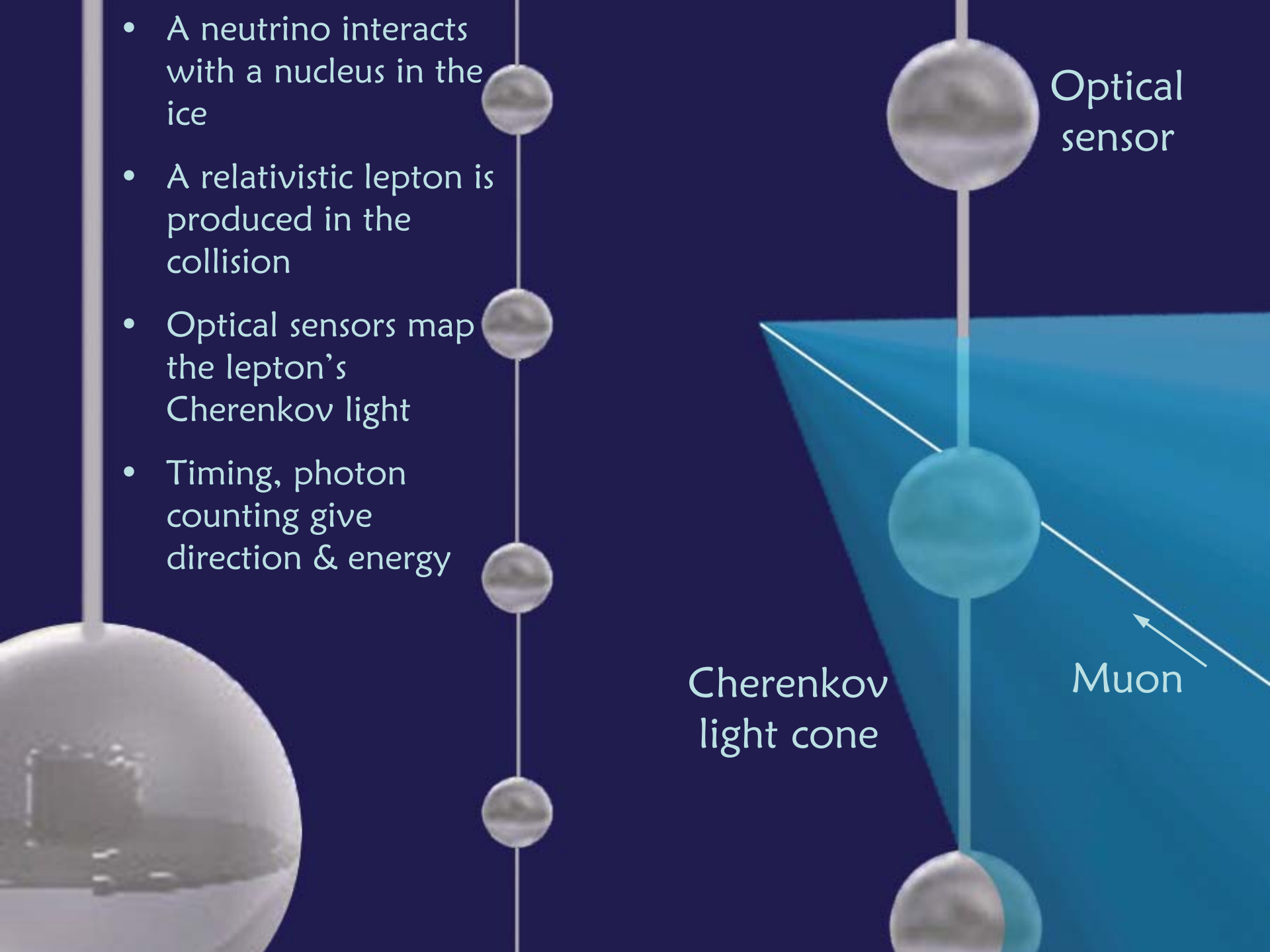
  $p + (p,\gamma) \rightarrow \pi^0 \rightarrow \gamma$

  but they are attenuated

- Need a site to produce high energy hadrons

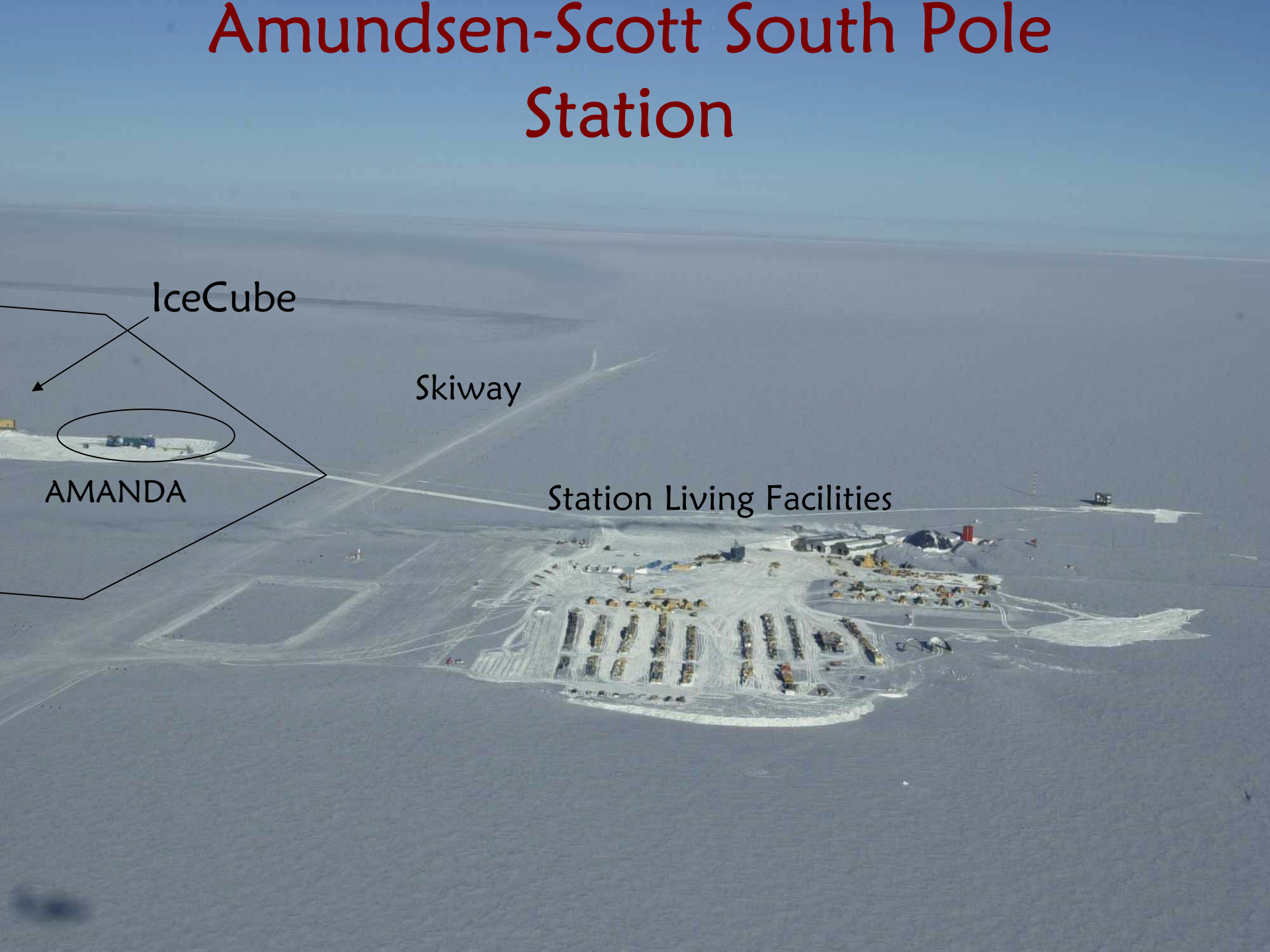


- A neutrino interacts with a nucleus in the ice
- A relativistic lepton is produced in the collision
- Optical sensors map the lepton's Cherenkov light
- Timing, photon counting give direction & energy



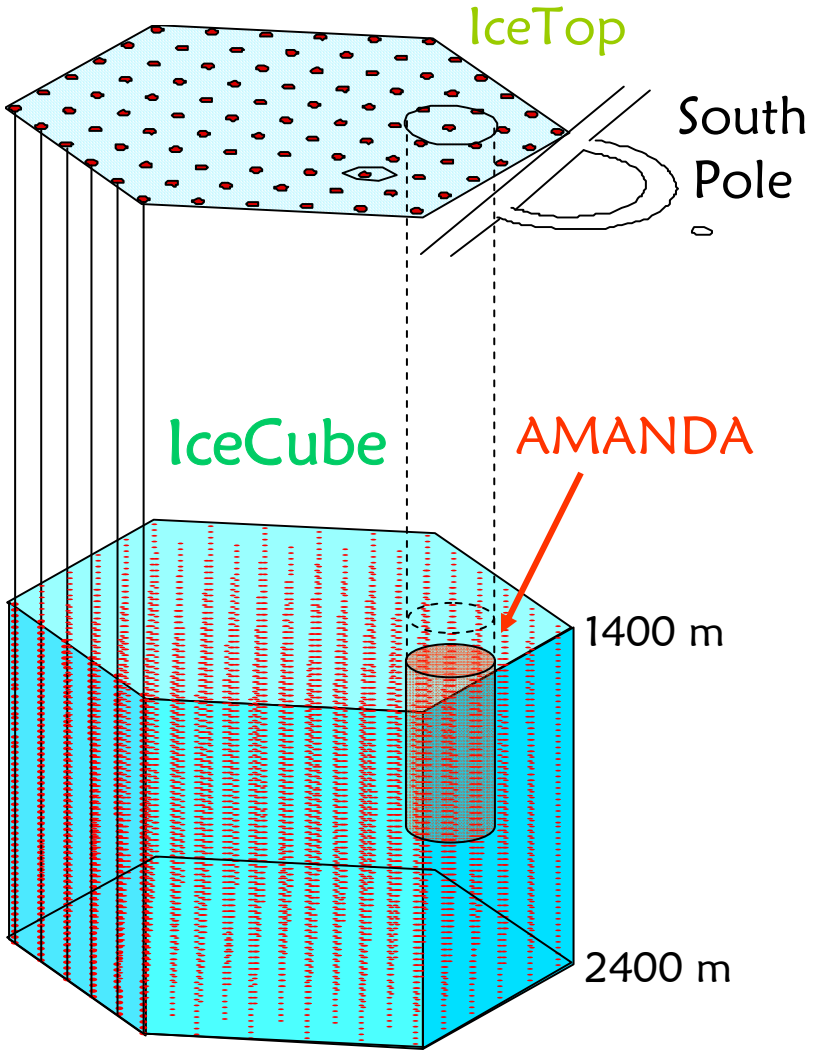
Amundsen-Scott South Pole Station

Amundsen-Scott South Pole Station



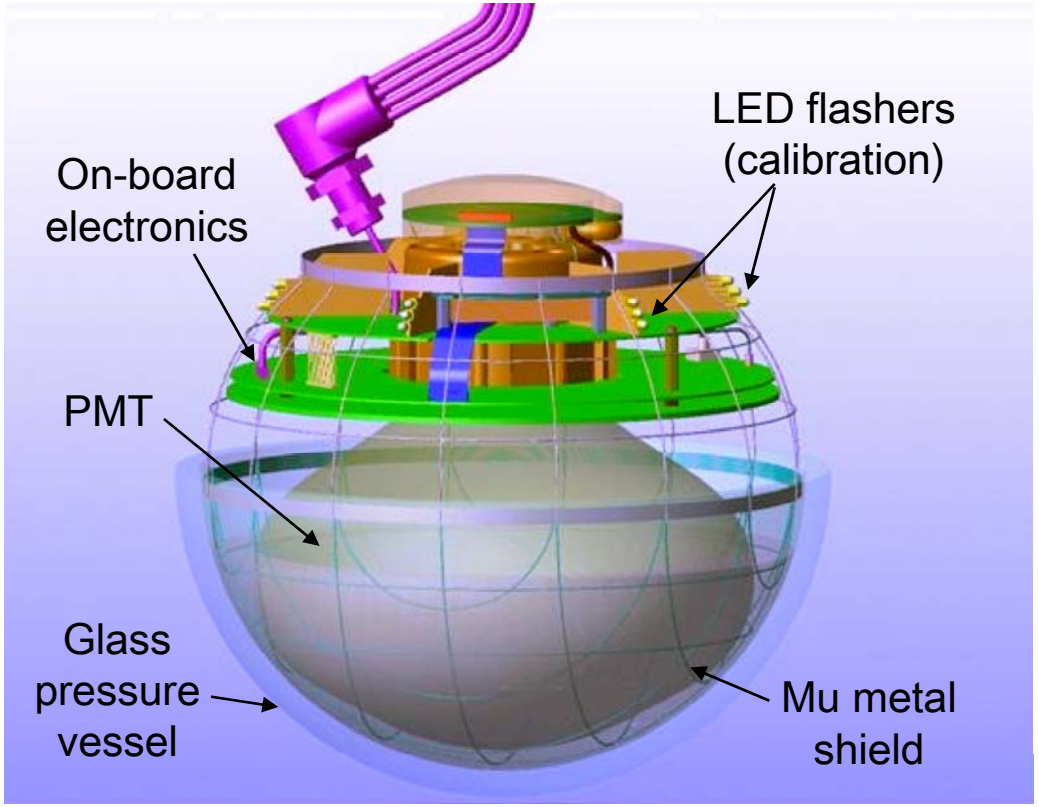
The IceCube Detector

- 1 km³ instrumented volume: 1 Gton of ice
- 4800 digital optical modules (DOMs) in the ice on 80 strings
- AMANDA will be enclosed within the array
- IceTop air shower array on the surface above the detector (80 stations, 320 DOMs)
- Geometry optimized for TeV—EeV neutrinos



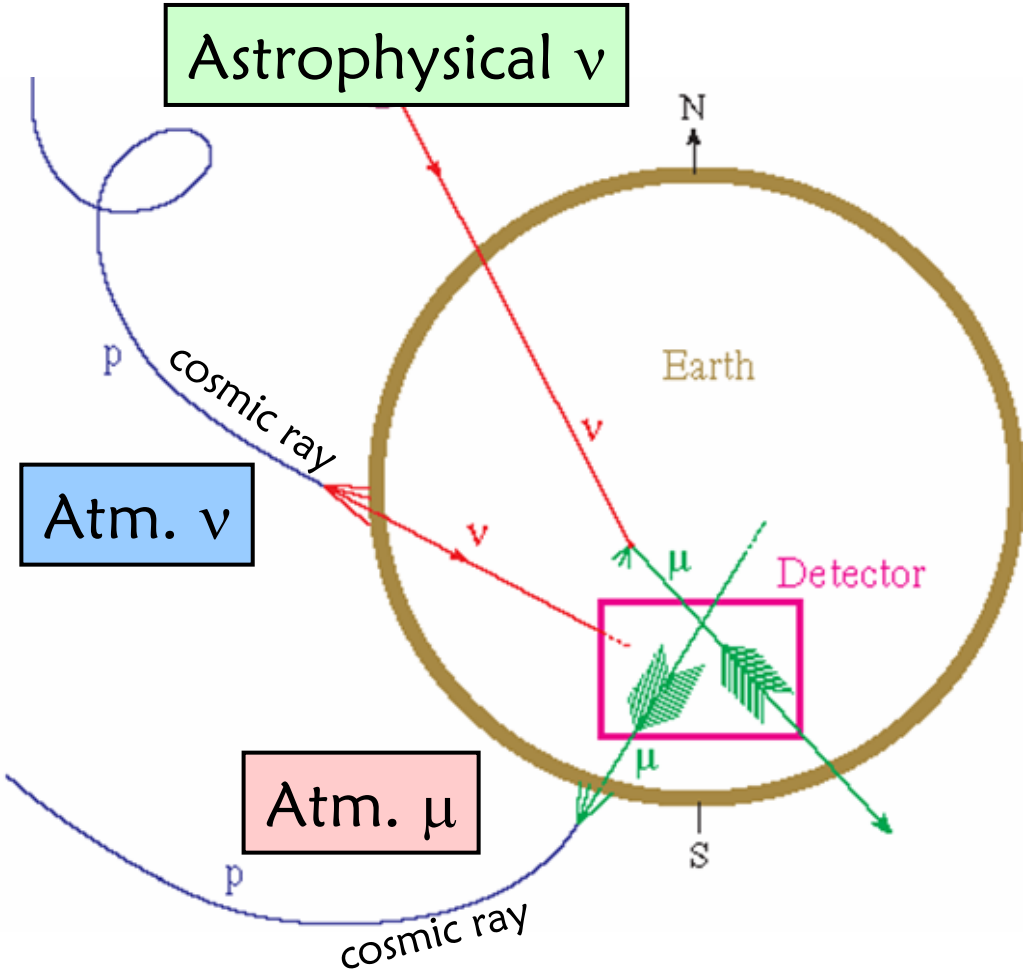
Digital Optical Modules (DOMs)

- 10” Hamamatsu PMT
- Glass pressure sphere
- Time resolution: 7 ns
- Dynamic range:
  - 200 photoelectrons / 15 ns
  - 2000 PE integrated / 5 μs
- Digitization rate:
  - 300 MHz for first 300 ns
  - 40 MHz for 6.4 μs
- Noise rate *in situ* < 1 kHz
- Deadtime < 1%



- All waveforms captured by on-board digitizers
  - Full digitized amplitude series transmitted for complex waveforms
  - Summary info extracted from simple waveforms

Atmospheric Muons & Neutrinos



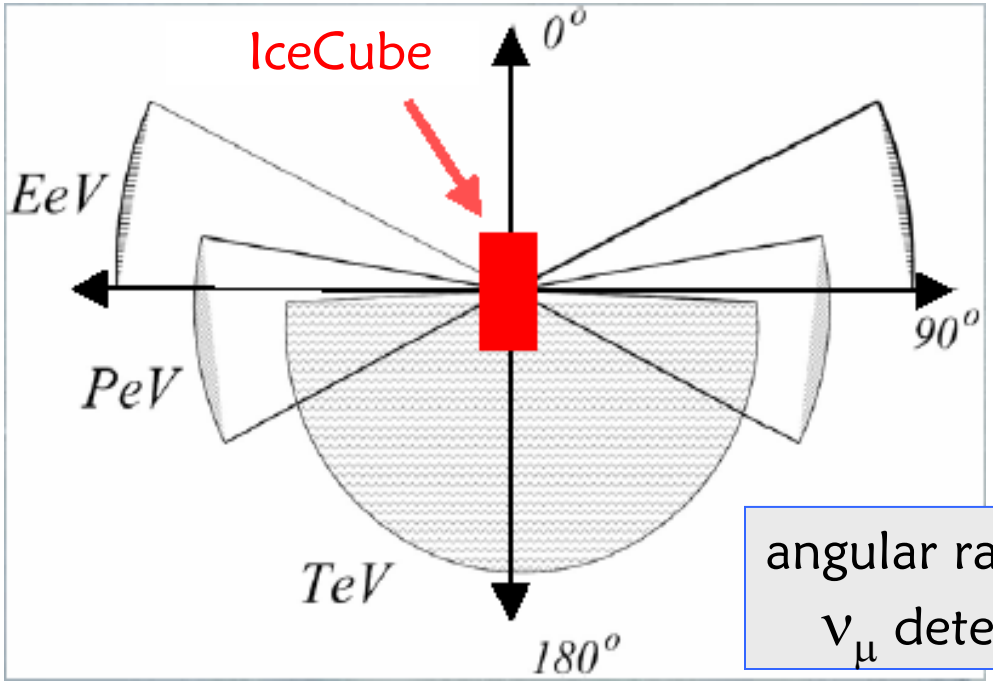
- "Atmospheric muons" from cosmic ray showers, penetrating to the detector from above
- "Atmospheric neutrinos" from the same air showers, forming a diffuse background and calibration source
- Astrophysical neutrinos

Muon Field of View

TeV: look down to avoid atmos. muons

PeV: Earth opaque, look horizontally

EeV: Can look above horizon – atmospherics are at lower energy



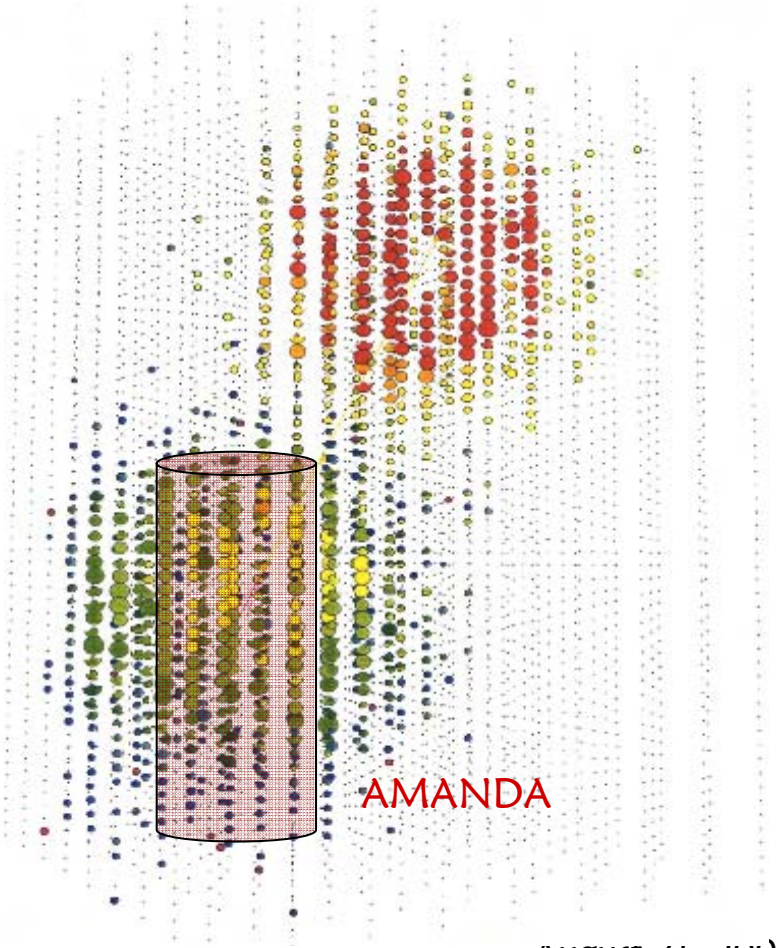
angular range for ν_μ detection

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

Tau Events

- Two cascades
  - νN interaction vertex
  - τ lepton decay
- Dim lepton track
  - ~50 m/PeV
  - Suppressed by $(m_\tau / m_\mu)^2$
- E » PeV: "Lollipop"
  - Dim track ending in a spectacular vertex

"Double Bang"
(Learned & Pakvasa 1995)



Tau Regeneration

(Halzen & Saltzberg)

Taus decay before they lose all their energy:

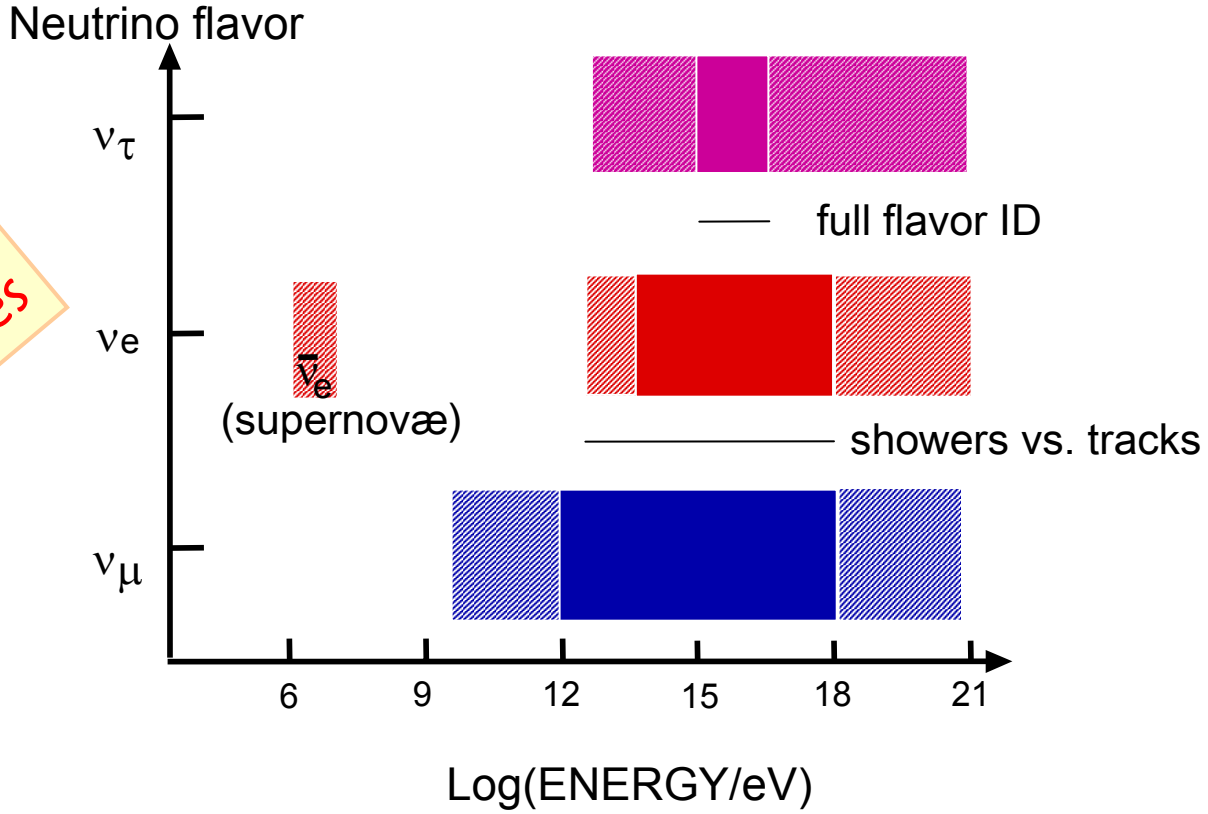
$$\nu_\tau + N \rightarrow \tau + X$$
$$\hookrightarrow \nu_\tau + \ell + \nu_\ell$$

Taus lose energy until their interaction length is comparable to the diameter of the Earth

→ PeV energies

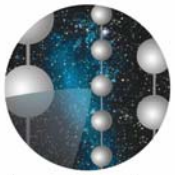
Earth is 'translucent' to tau neutrinos – full sky!

Neutrino Sensitivity



Conservative: current techniques

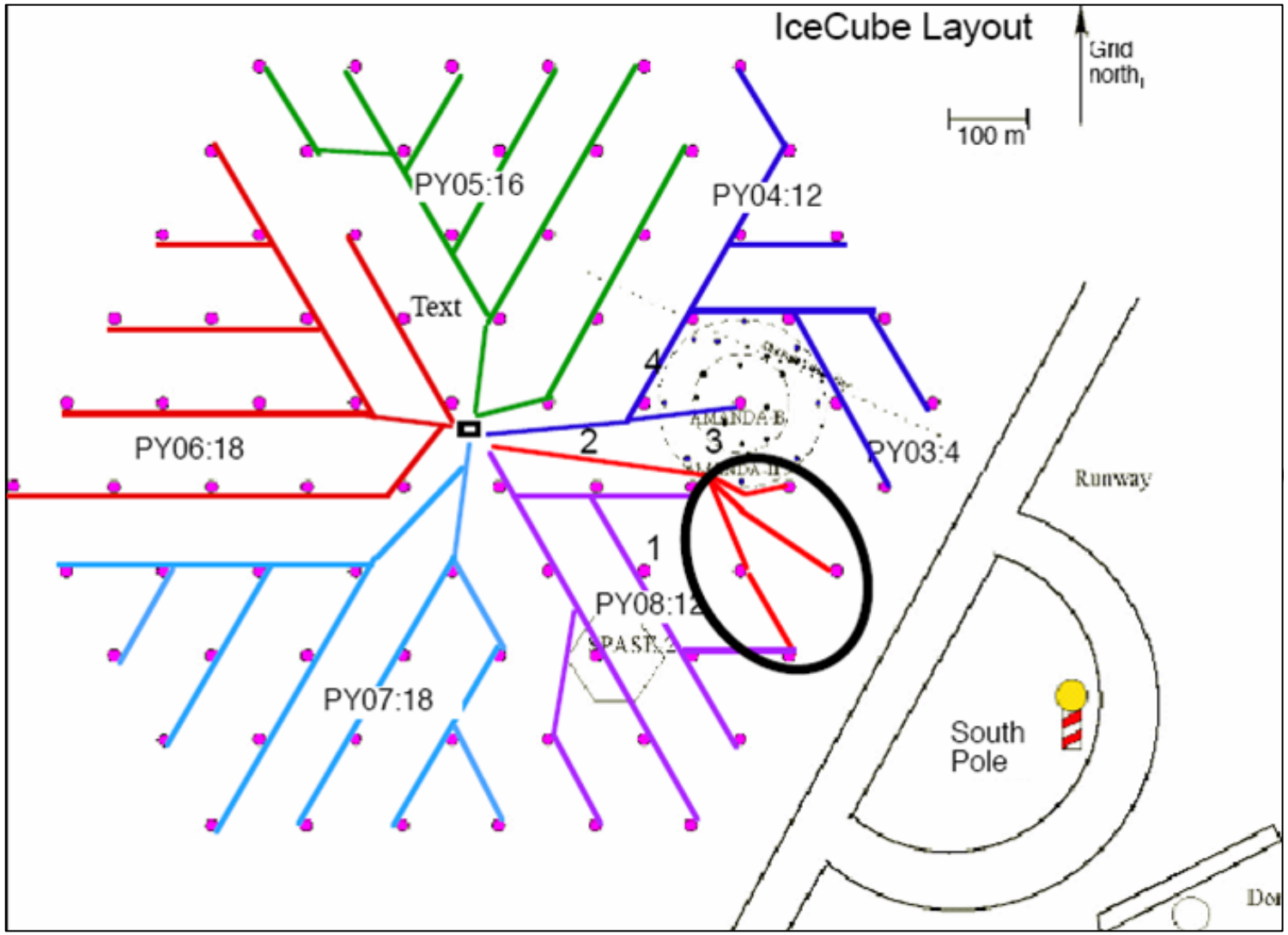
- Sensitive to all flavors of neutrinos
  - Solid areas show best reconstruction: flavor, direction, energy
  - Hatched areas show triggers, more difficult reconstruction.

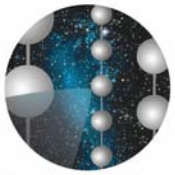


IceCube Project Status

- Funding approved, project moving forward!
- First four strings to be deployed January 2005
- Deployment of remaining strings 2005-2010
- Strings will be brought on line as they are deployed during construction phase
- 1 km^3-yr of data by 2007!

IceCube Project Status





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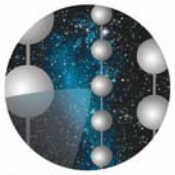
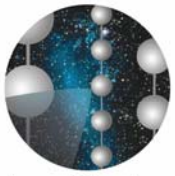


IceCube Prospects

- Larger effective area
  - More events → better sensitivity
- Better sensor information
- More complete event information
  - Flavor identification
  - Angular, energy reconstruction
  - Background rejection
- New results from HESS, Milagro suggest there are surprises out there!



IceCube Physics Topics

- Atmospheric neutrino spectrum
- Cosmic ray composition above the knee
- Diffuse extraterrestrial neutrino fluxes
- High energy neutrino point sources
- Ultrahigh energy cosmogenic neutrinos (GZK)
- Neutrinos from GRBs
- Galactic supernovæ (SNEWS)
- Ultralong baseline neutrino oscillations
- Supersymmetry and Dark Matter
  - WIMP annihilations in the Sun or Earth
  - Long-lived sleptons (NLSP)
- High energy transient phenomena (topological defects, relics,…)
- TeV-scale extra dimensions, electroweak instantons, etc.
- Relativistic magnetic monopoles

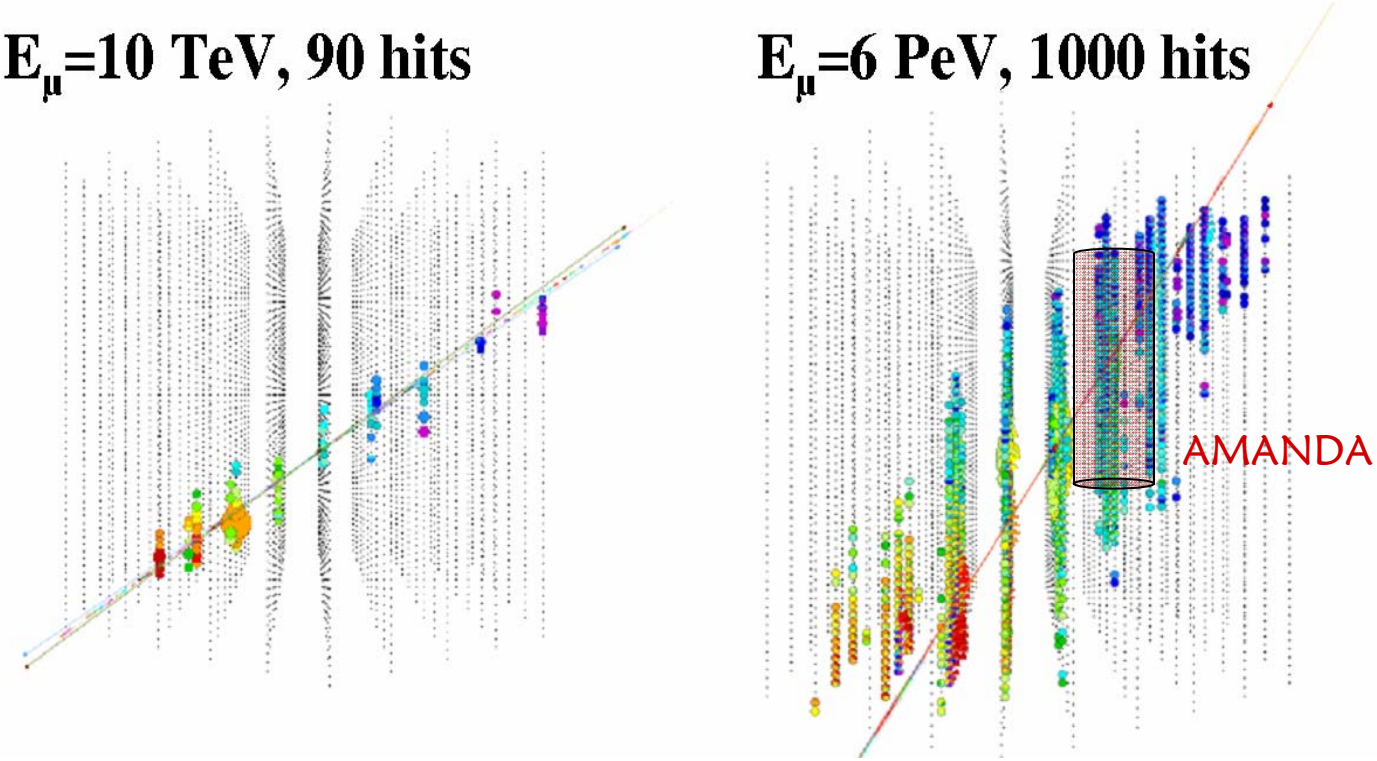
…and new discoveries!

Old and New South Pole Stations

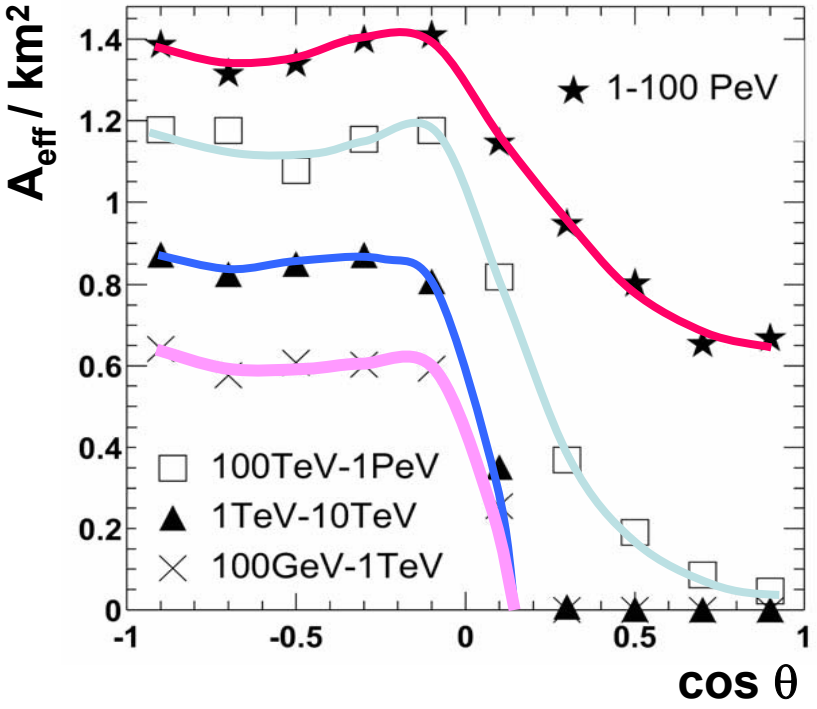
Muon Tracks

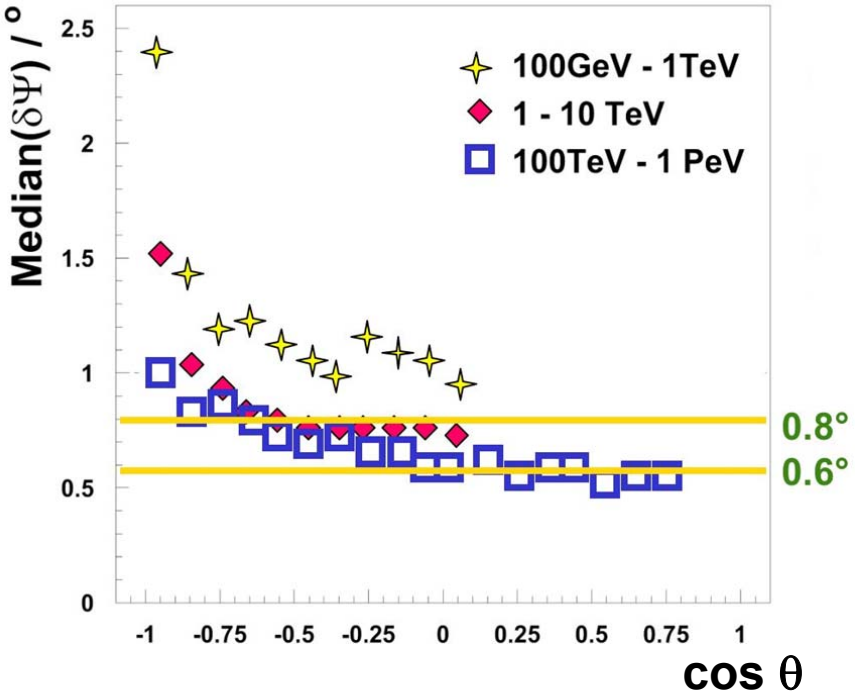
Long tracks: Angular resolution, flavor identification

Energy measured from brightness



IceCube Muon Response





- Results with simulated AMANDA hardware, software
- Big improvements possible – waveforms, more hits, better noise reduction, reconstruction techniques

Cascade Resolution