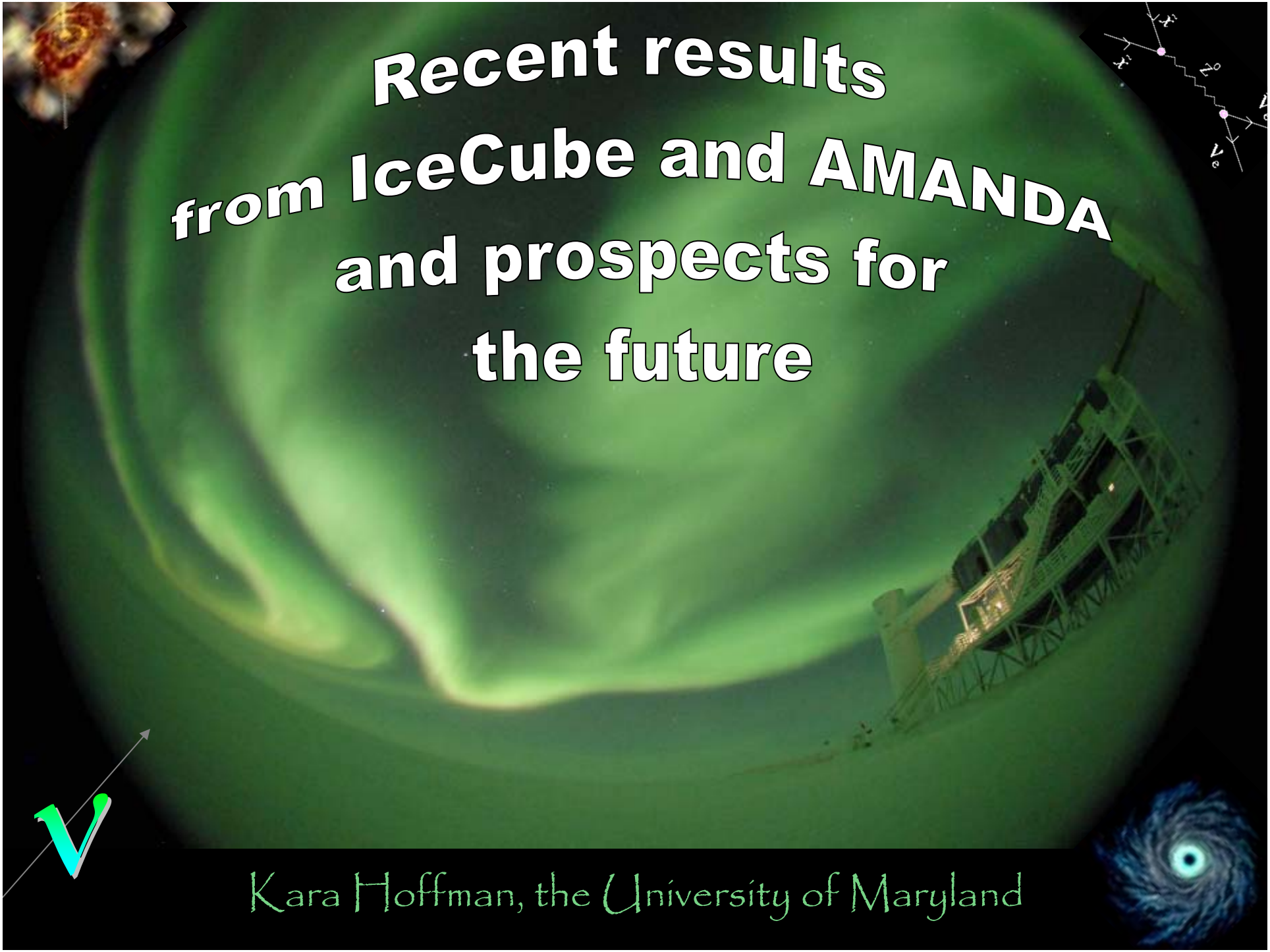
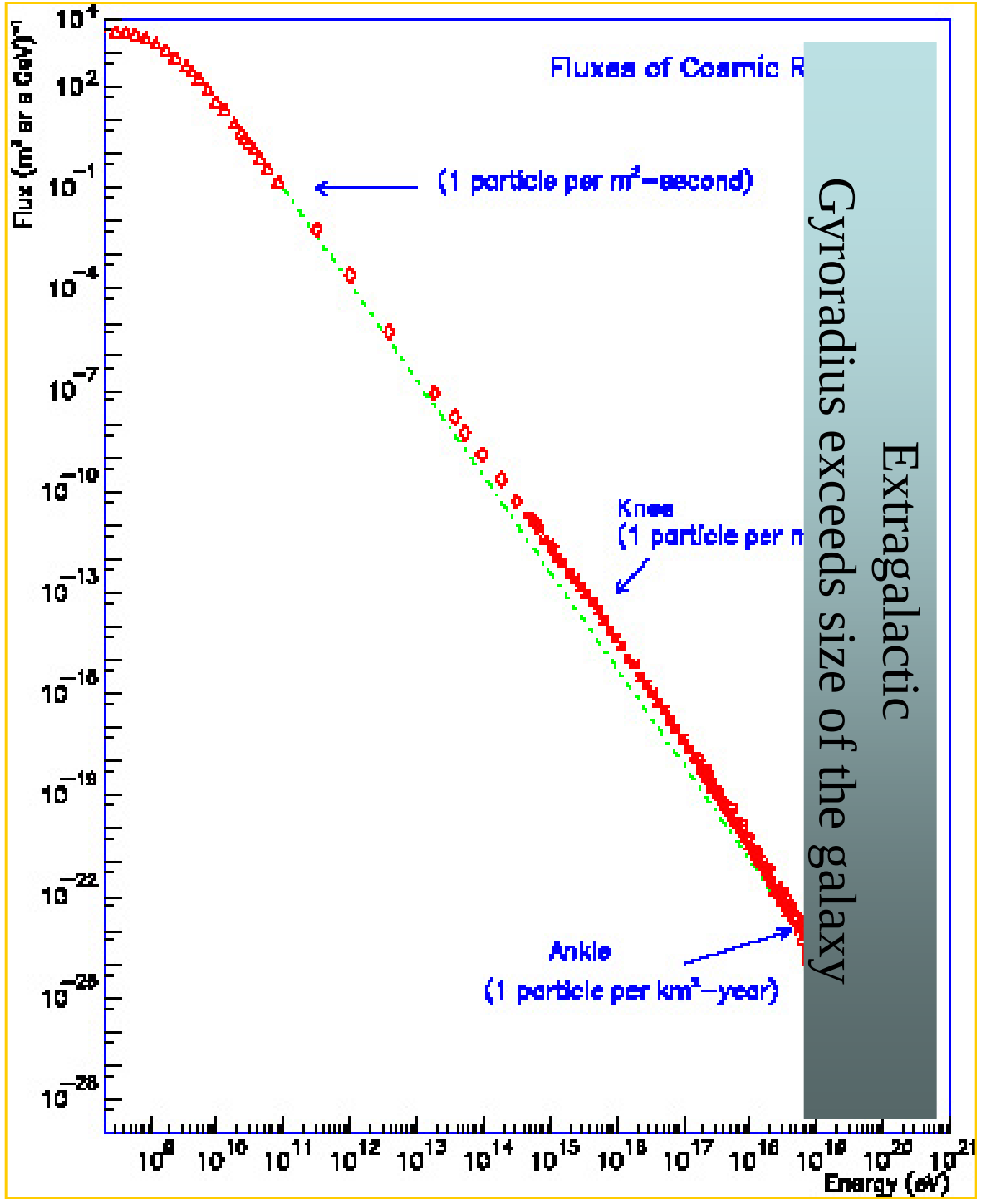

Recent results
from IceCube and AMANDA
and prospects for
the future
Kara Hoffman, the University of Maryland

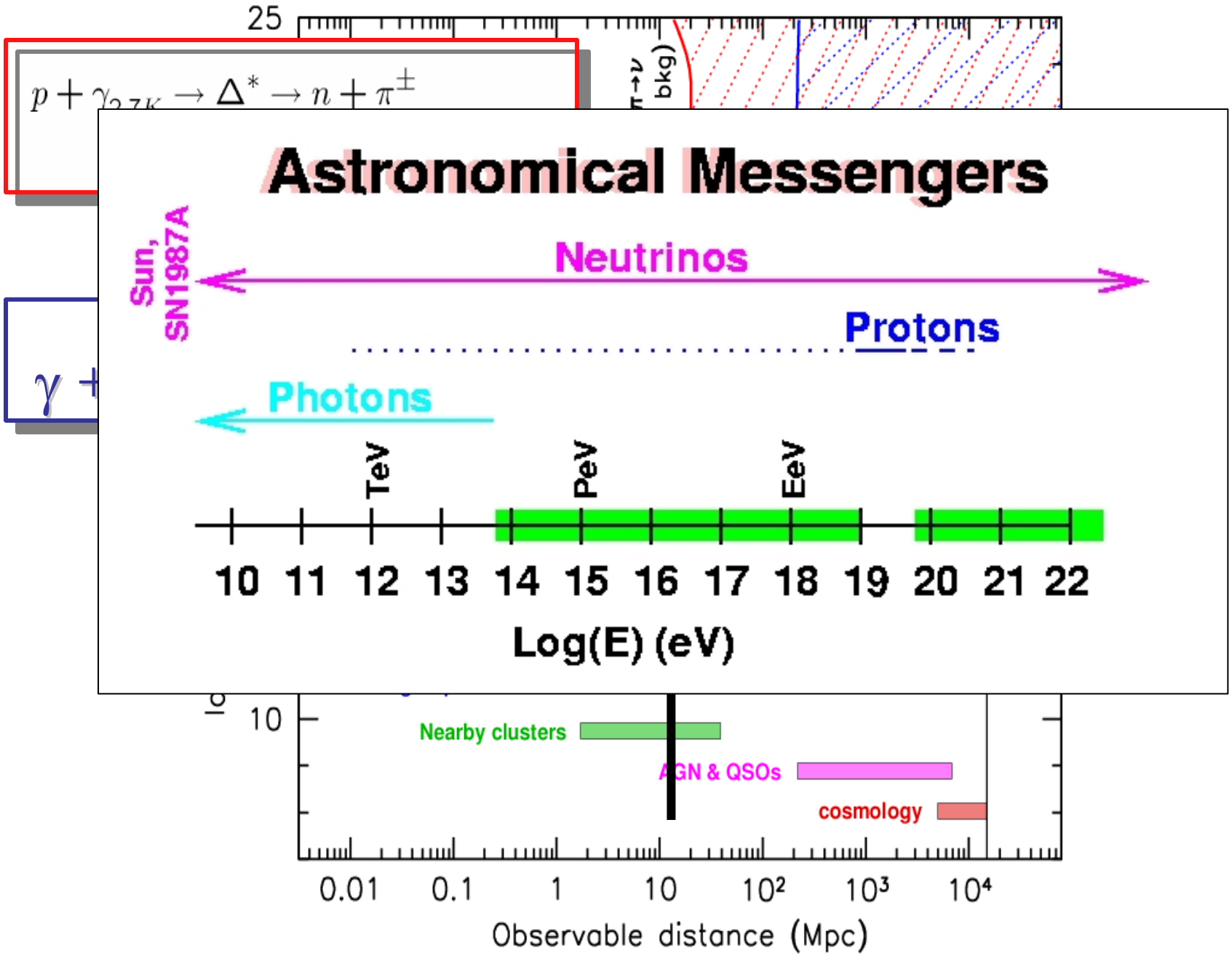
Cosmic ray Spectrum

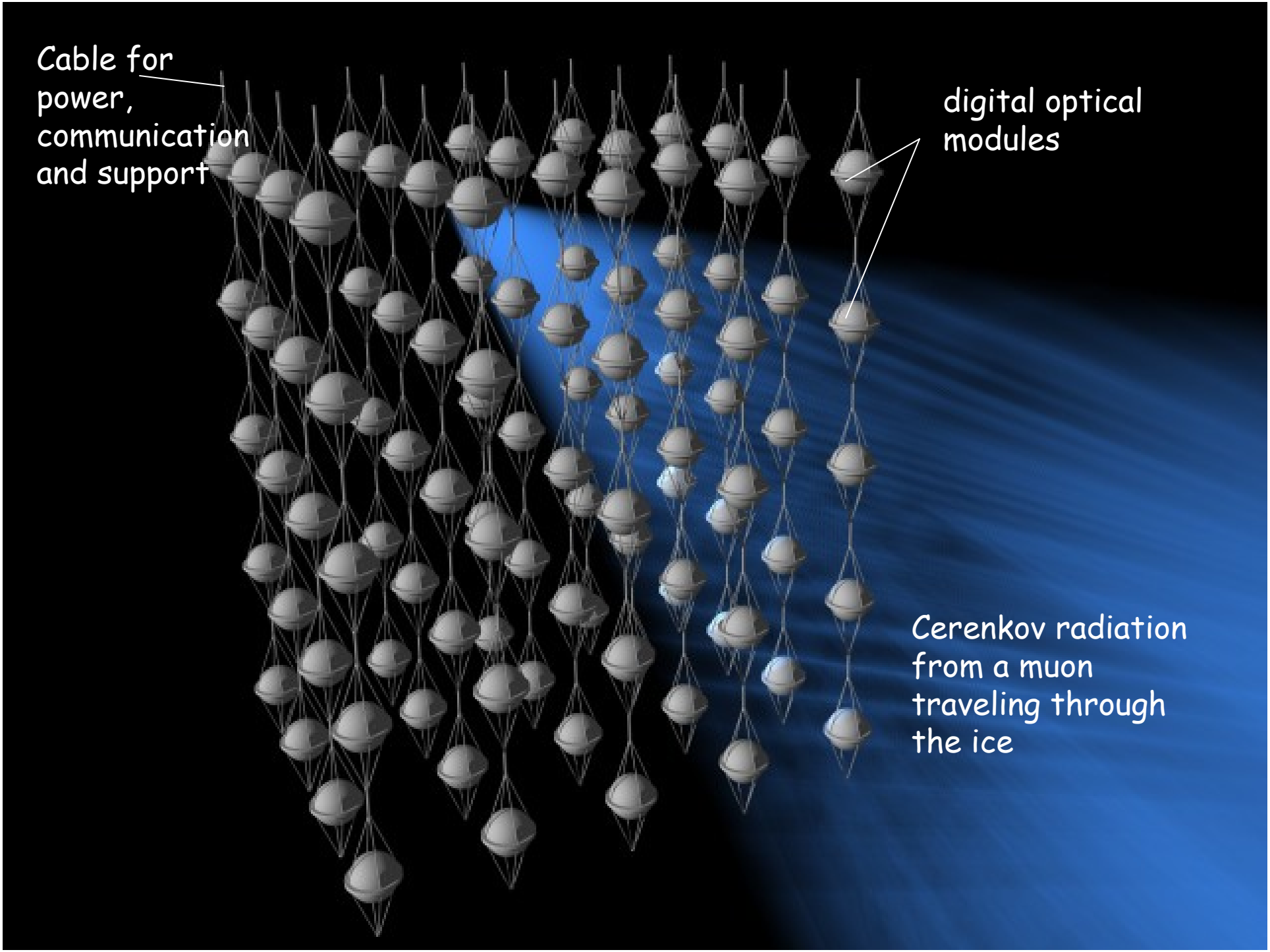
cosmic rays have been observed with energies in excess of 10^20 eV

the origin of these energetic particles remains an enigma

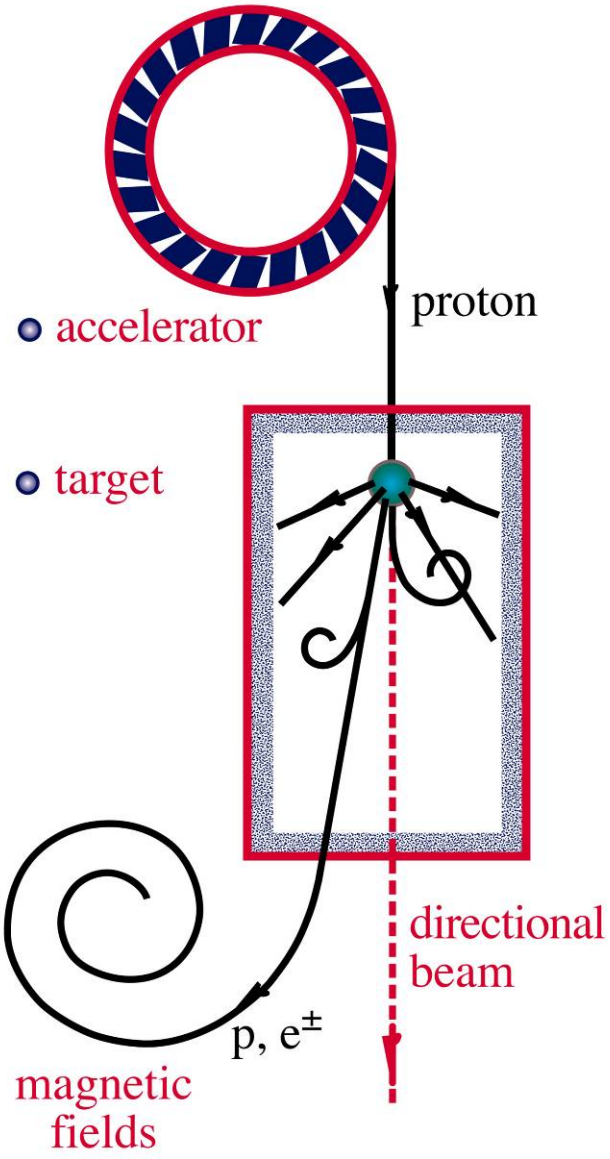
the observed fluxes of these particles sets the scale for cosmic ray observatories

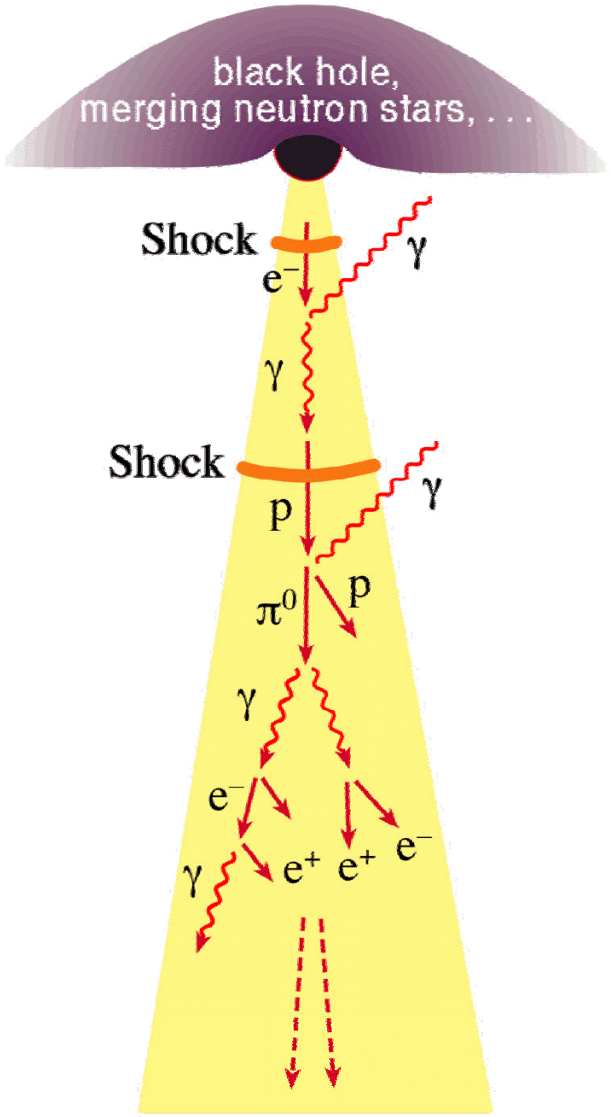



$p + \gamma_{2.7K} \to \Delta^* \to n + \pi^{\pm}$
$\gamma +$
25
bkg)
Astronomical Messengers
Sun, SN1987A
Neutrinos
Protons
Photons
TeV
PeV
EeV
10 11 12 13 14 15 16 17 18 19 20 21 22
Log(E) (eV)
10
Nearby clusters
AGN & QSOs
cosmology
0.01 0.1 1 10 10^2 10^3 10^4
Observable distance (Mpc)


Cable for power, communication and support
digital optical modules
Cerenkov radiation from a muon traveling through the ice

Why neutrinos make a good proxy





AMANDA the Antarctic Muon and Neutrino Array

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

IceCube

IceTop

Air shower detector

80 pairs of ice Cherenkov tanks

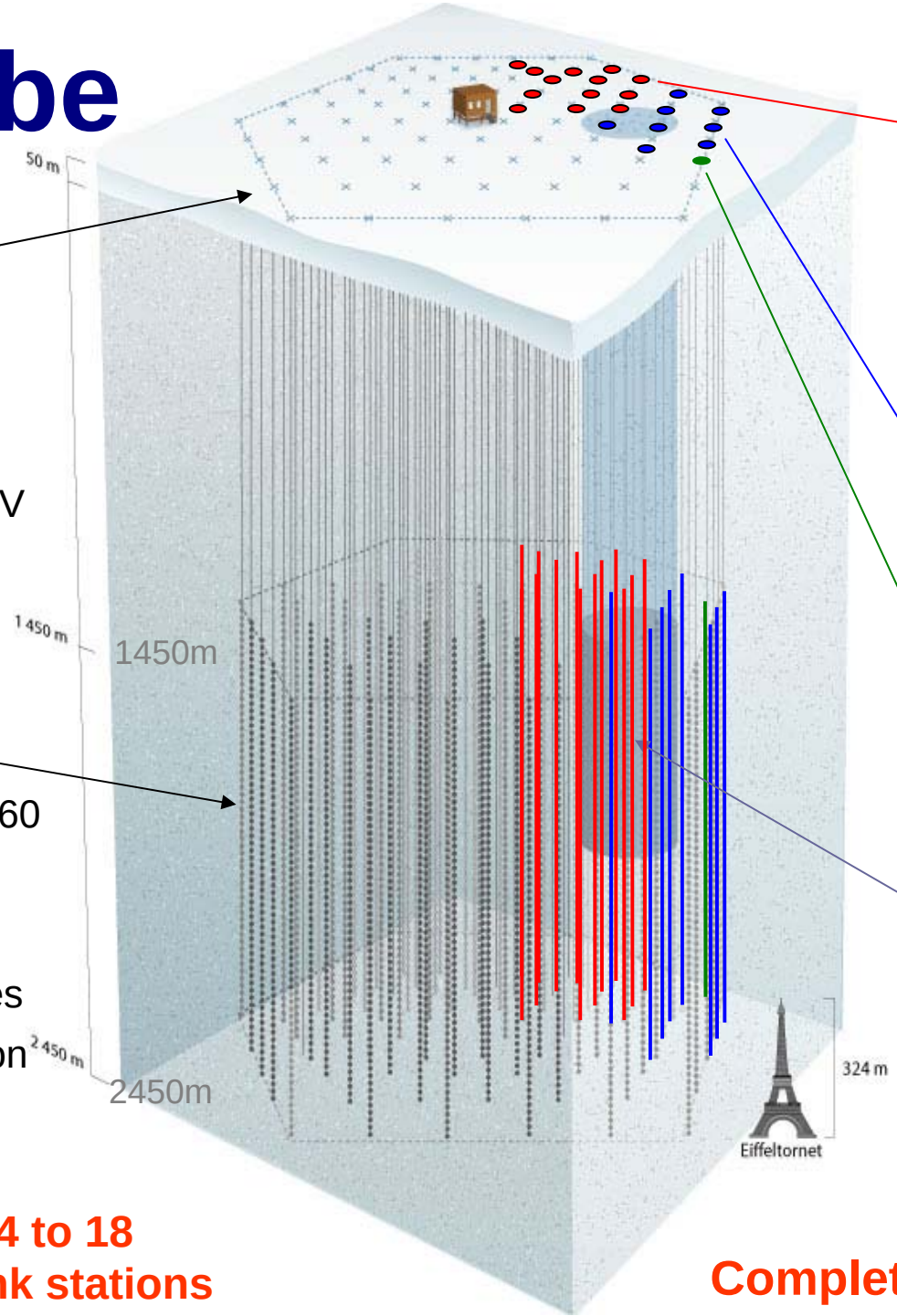
Threshold ~ 300 TeV

InIce

Planned 80 strings of 60 optical modules each

17 m between modules

125 m string separation



2006-2007:

13 strings deployed

Current configuration
- 22 strings
- 52 surface tanks

2005-2006: 8 strings

2004-2005 : 1 string

AMANDA-II

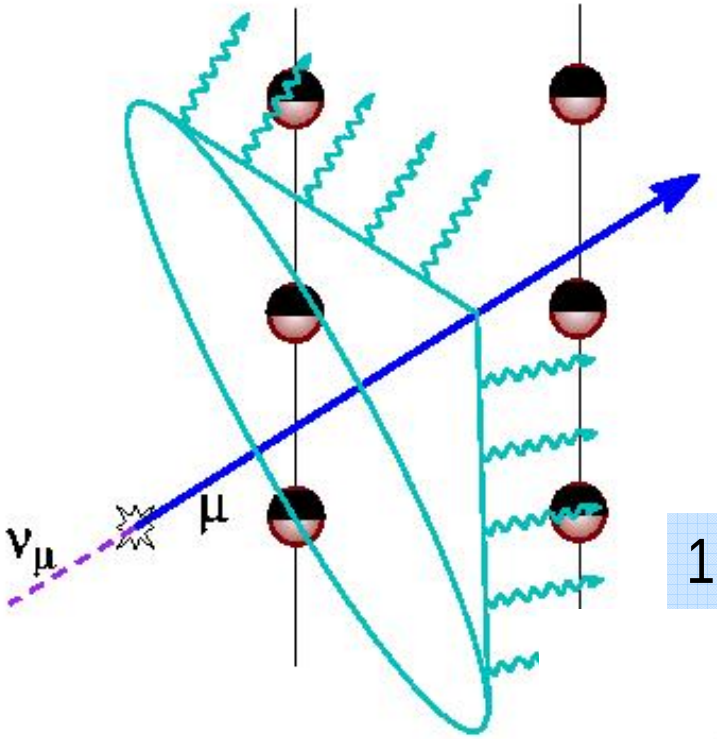
19 strings

677 modules

AMANDA now operating as part of IceCube

2007/08: add 14 to 18 strings and tank stations

Completion by 2011.

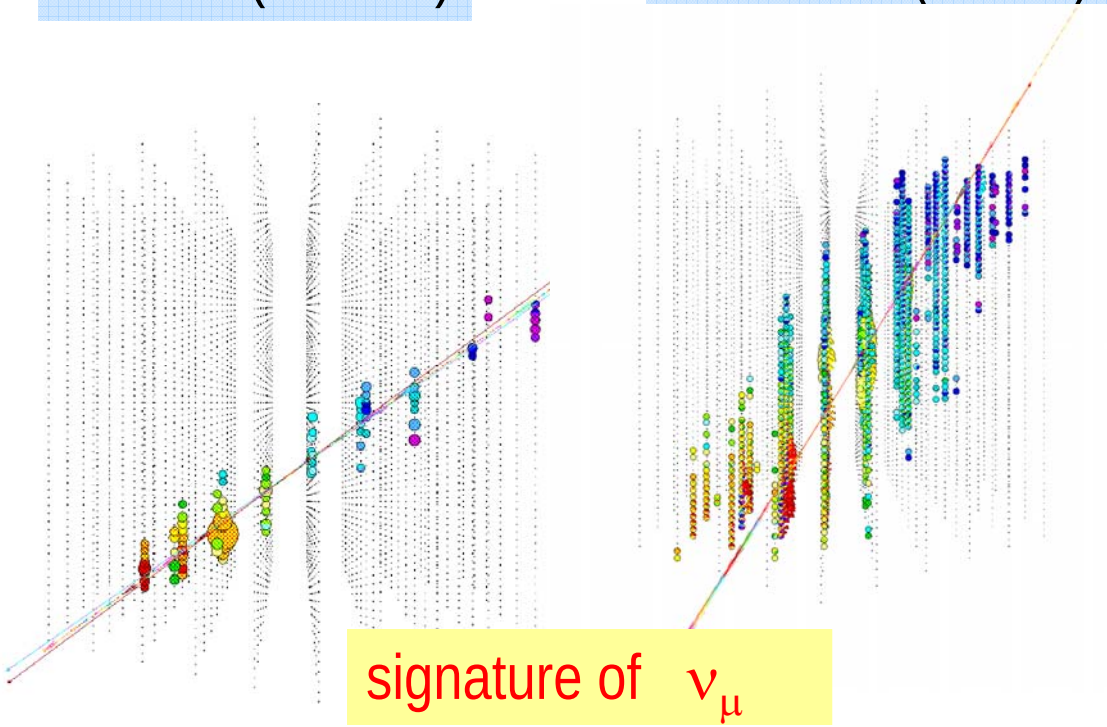


Muon signatures

- Crude energy measurement can be obtained by counting the number of fired DOMs
- Direction determined by time of arrival of cerenkov light
- Muon and neutrino colinear to 1 degree or at 1 TeV

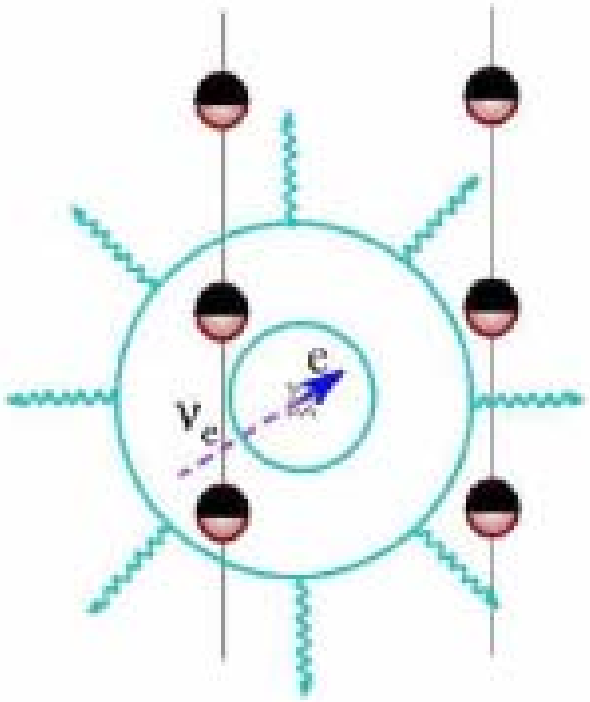
10^{13} eV (10 TeV)

$6x10^{15}$ eV (6 PeV)

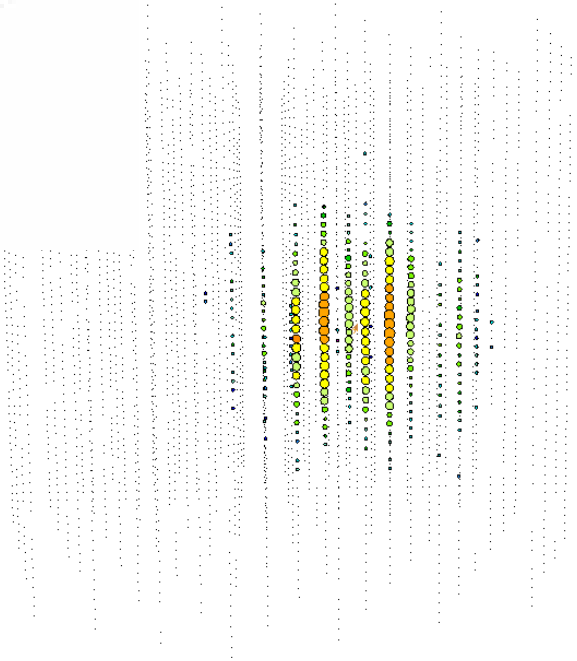


signature of ν_μ

Cascades

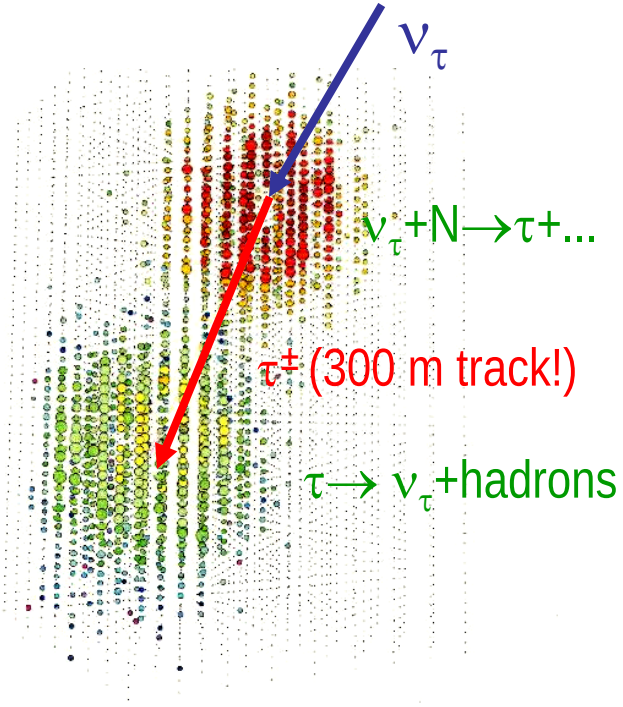


375 TeV



signature of ν_e

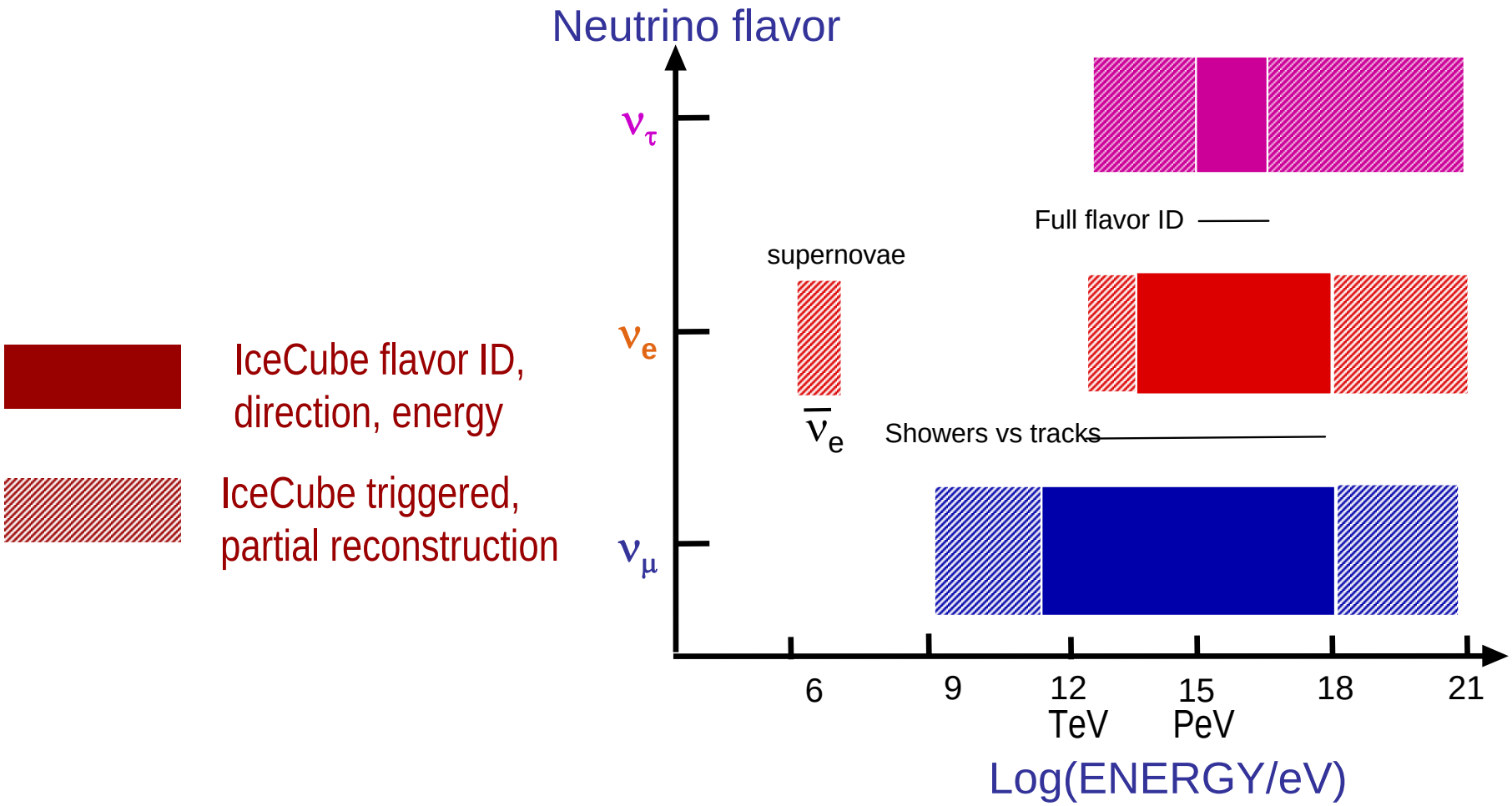
Multi-PeV



signature of ν_τ

Tau neutrinos only expected over a very long baseline since oscillations make ratios of neutrino flavors 1:1:1.

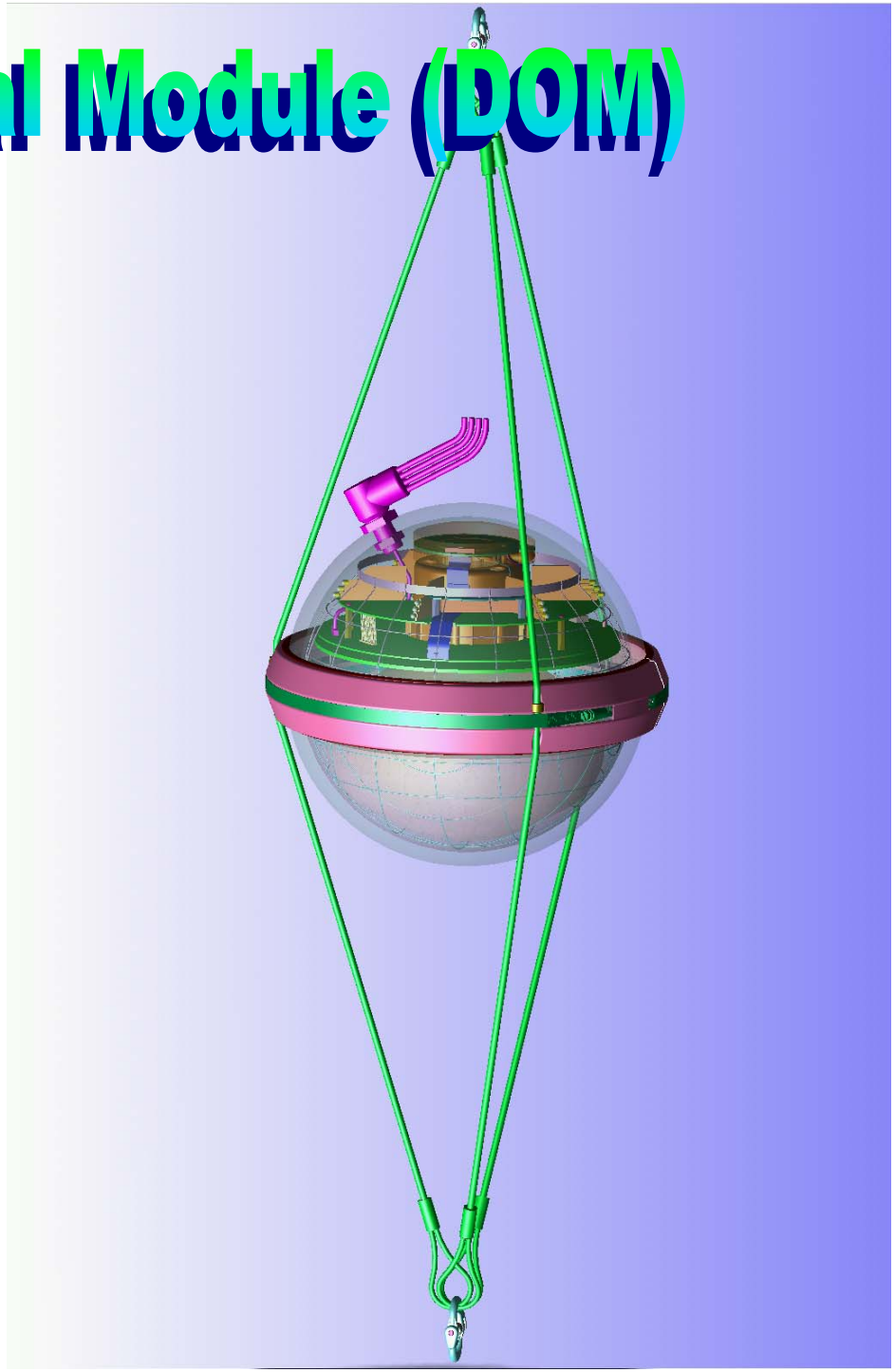
IceCube energy and directional resolution, flavor discrimination



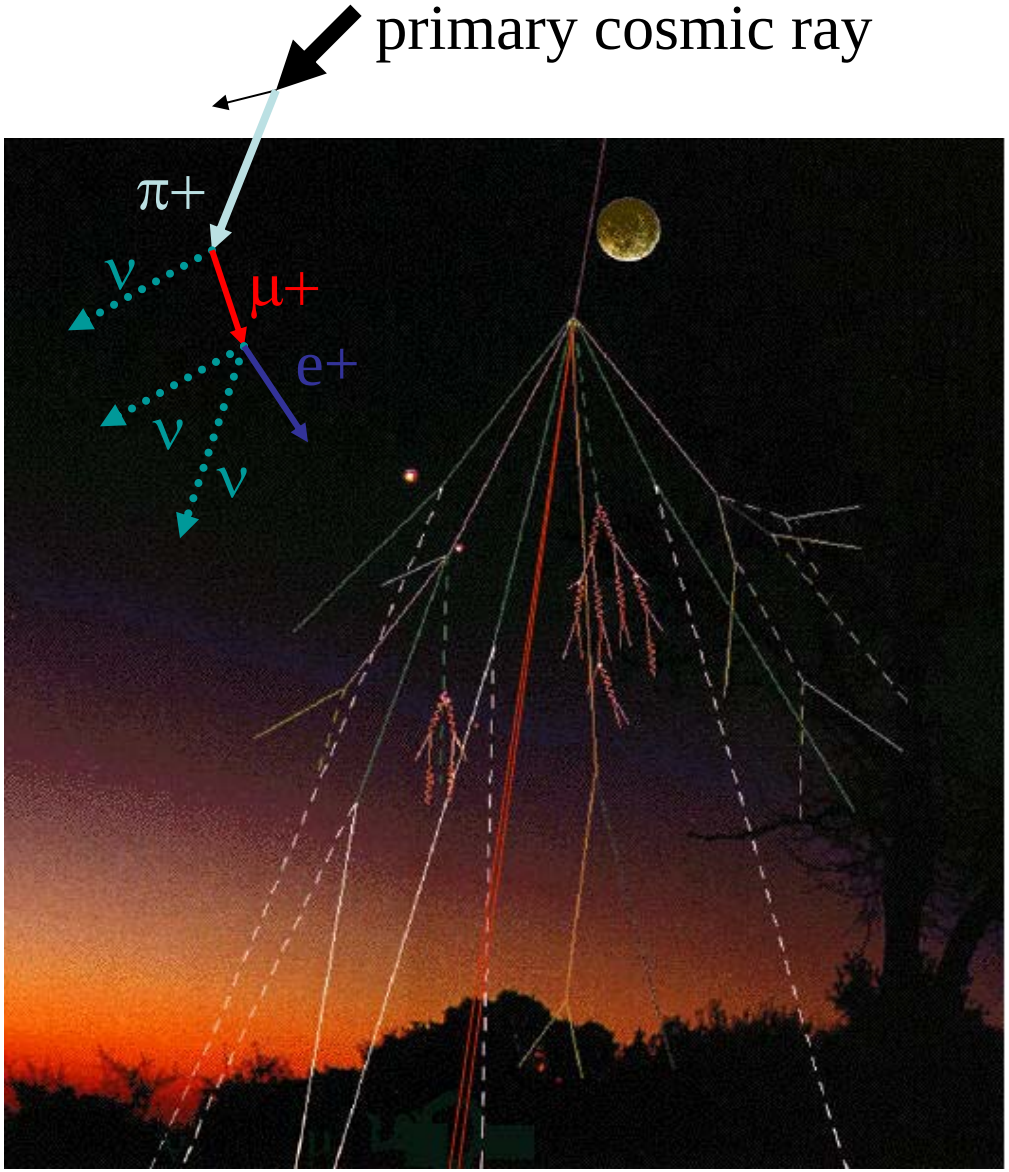
The Digital Optical Module (DOM)

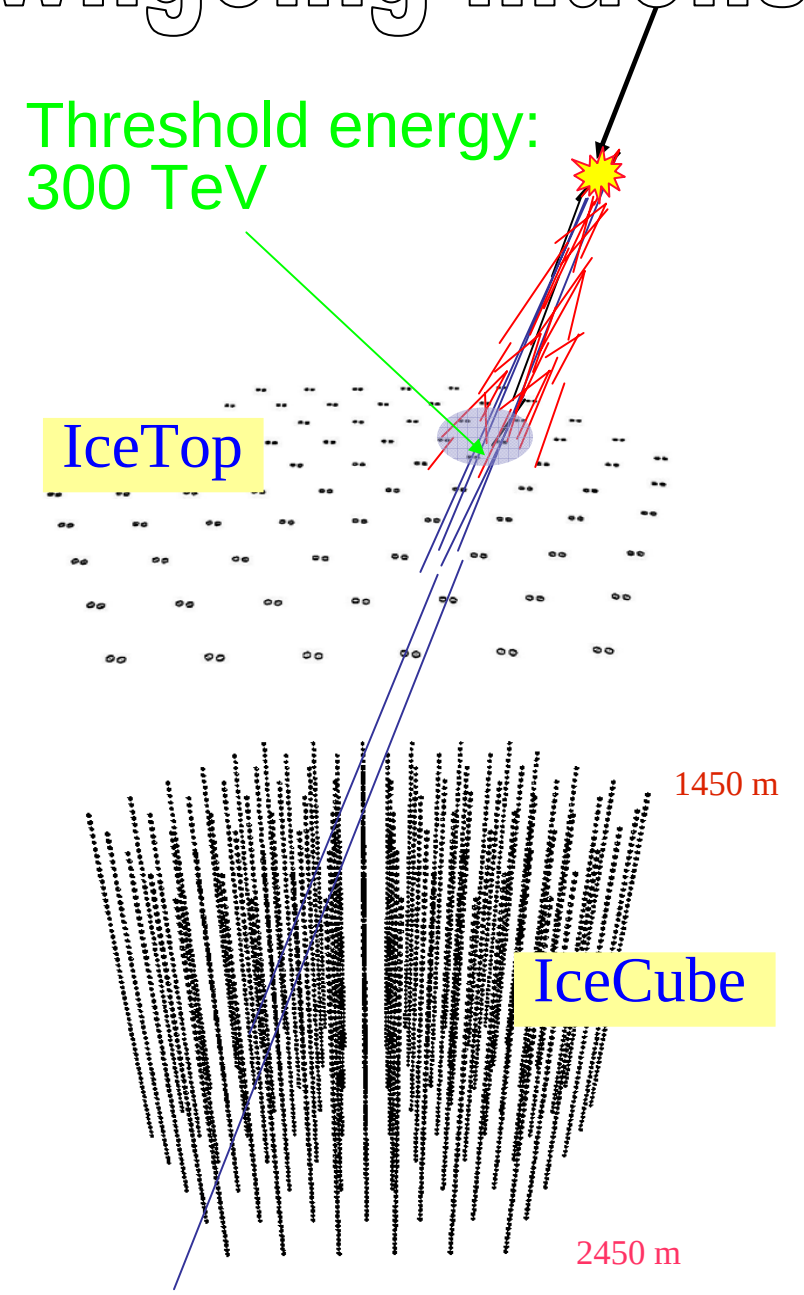
- 10” PMT in 13” Glass sphere
- Mother Board:
  - 2 ASIC (ATWD) chips to digitize PMT signals in 3.3ns samples
  - FPGA for DAQ
  - CPUs and SDRAM for communication, calibration, buffering data
- High Voltage Generator & Base Board
- LED Board for calibration

- dynamic range: 1 pe to 25000 pe
- Low photon counting background: in-ice rates of order 700 Hz
- Complete, self-contained, reconfigurable digital data acquisition system
- High-precision timing over vast network of 1000’s of sensors to nanosecond scale.

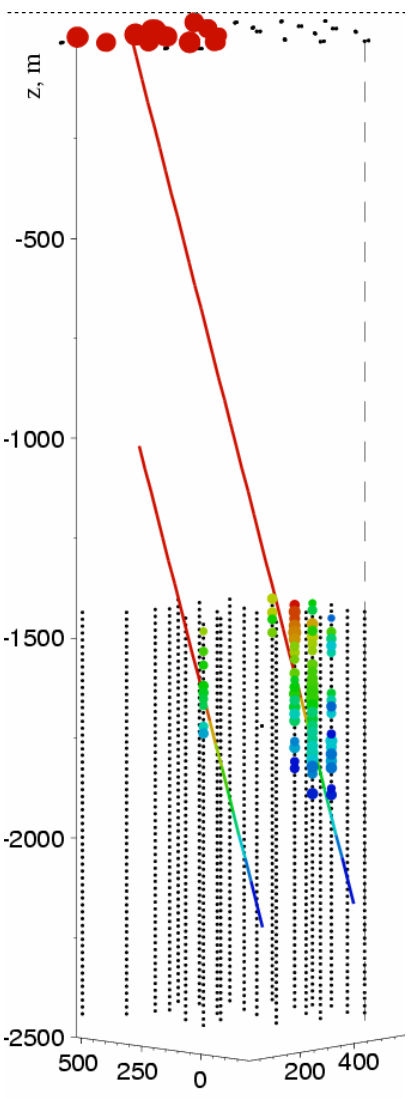


Cosmic rays and downgoing muons





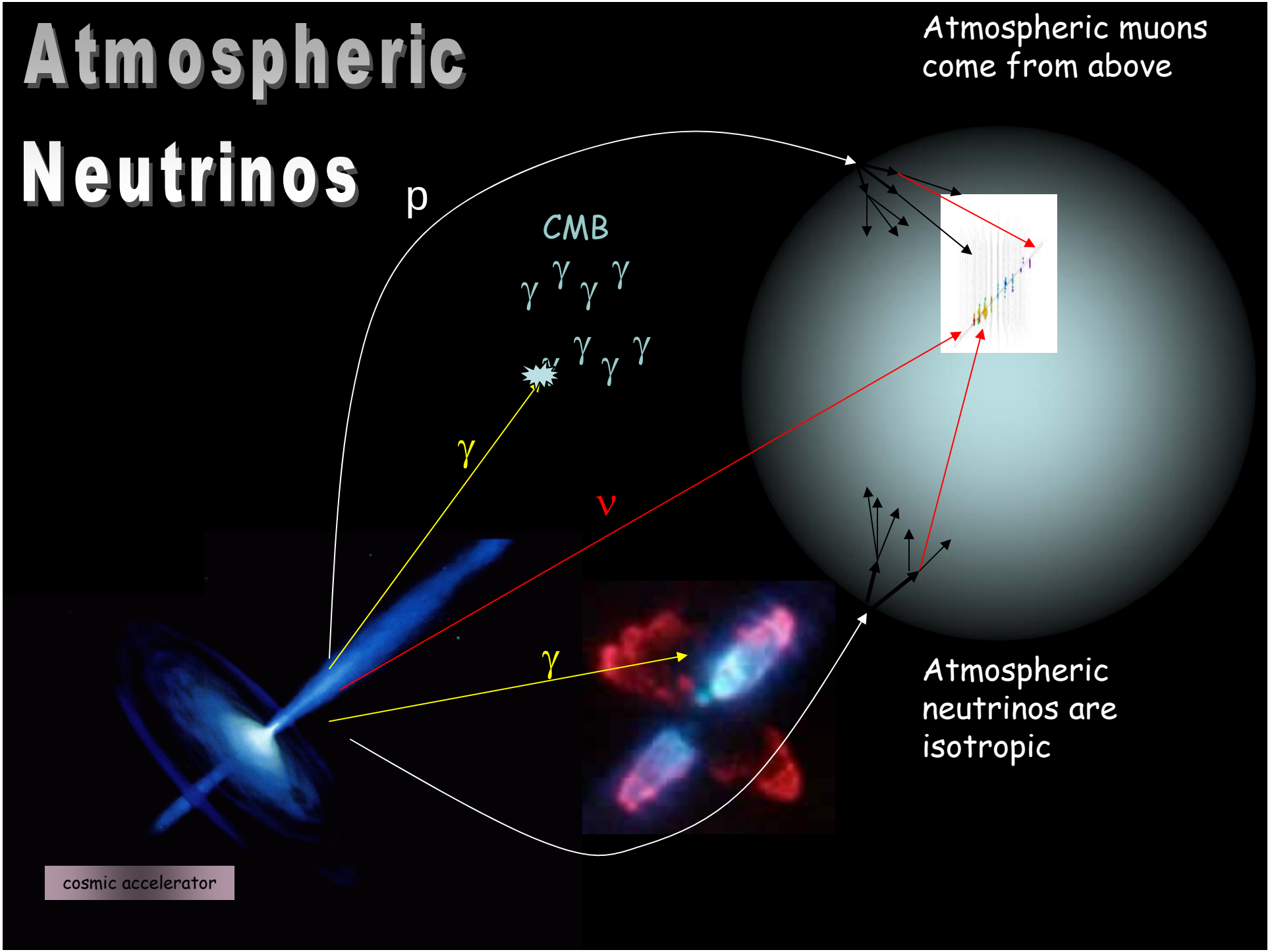
Atmospheric muons as a "testbeam"

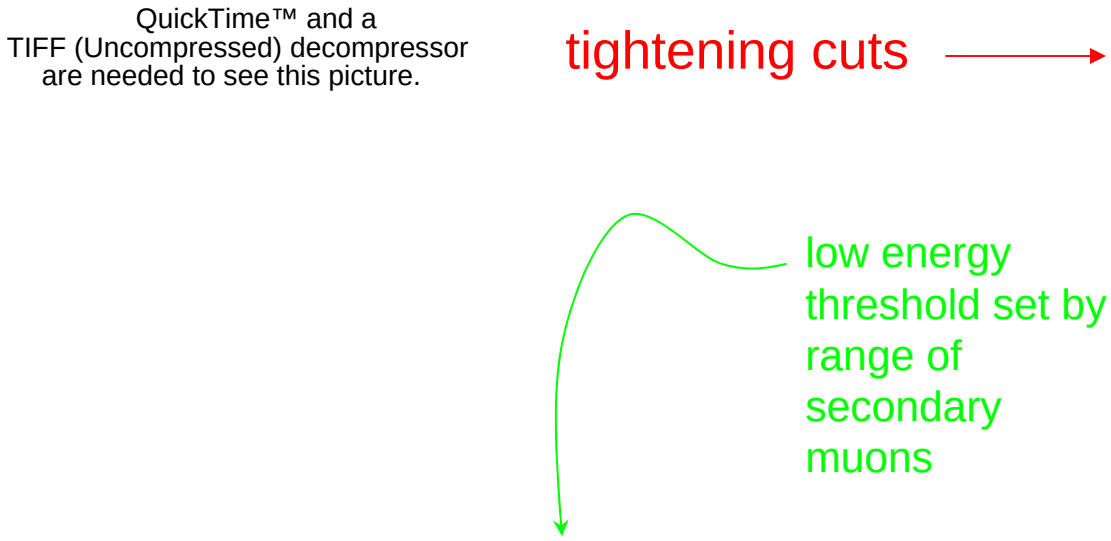


- Compare independent zenith angle reconstructions
- Plot time between hits in in-ice and ice-top DOMs versus the distance between them

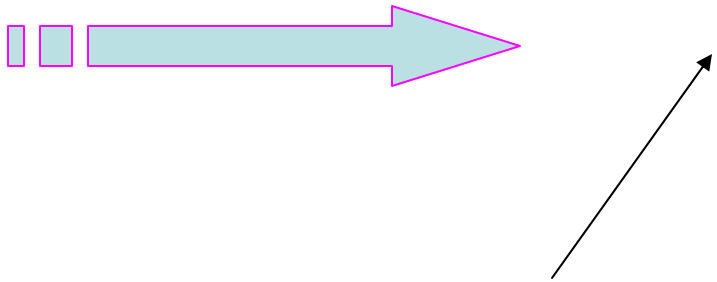
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Atmospheric Neutrinos




QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.
tightening cuts
low energy
threshold set by
range of
secondary
muons

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



Point source search: IC9

0.25° x 0.25° grid

maximum likelihood analysis

source strength weight

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

probability distribution of signal events (point spread ~2 deg.)

probability distribution of background events

10-20% improved sensitivity over binned analysis

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

hottest spot: 3.35 σ

60% of background trials gave a chance clustering of events at 3.35 σ somewhere in the sky

Source catalogue

Perform maximum likelihood test for 26 well motivated neutrino source candidates chosen a priori

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

galactic plane

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

- MGRO J2019+37, TeV J2033+4130
- Blazars: Mrk 421, Mrk 501, 1ES 1959+650, 1ES 2344+514, H 1426+428, BL Lac (HBL), 3C66A (LBL), 3C 454.3 , 4C 38.41, PKS 0528+134, 3C 273, M87, Per A, Cyg A (Radio loud and GeV EGRET Quasars)
- μ-quasars: SS433, Cyg X-3, Cyg X-1, LSI +61 303 (pulsar?) (HMXB), GRS 1915+105, XTE J1118+480, GRO J0422+32 (LMXB)
- SNRs: Crab, Geminga, Cas A

Neutrinos i
coincidenc
gamma-ray

C

A Distant GR

GLAST launch
in 2009!

IANDA

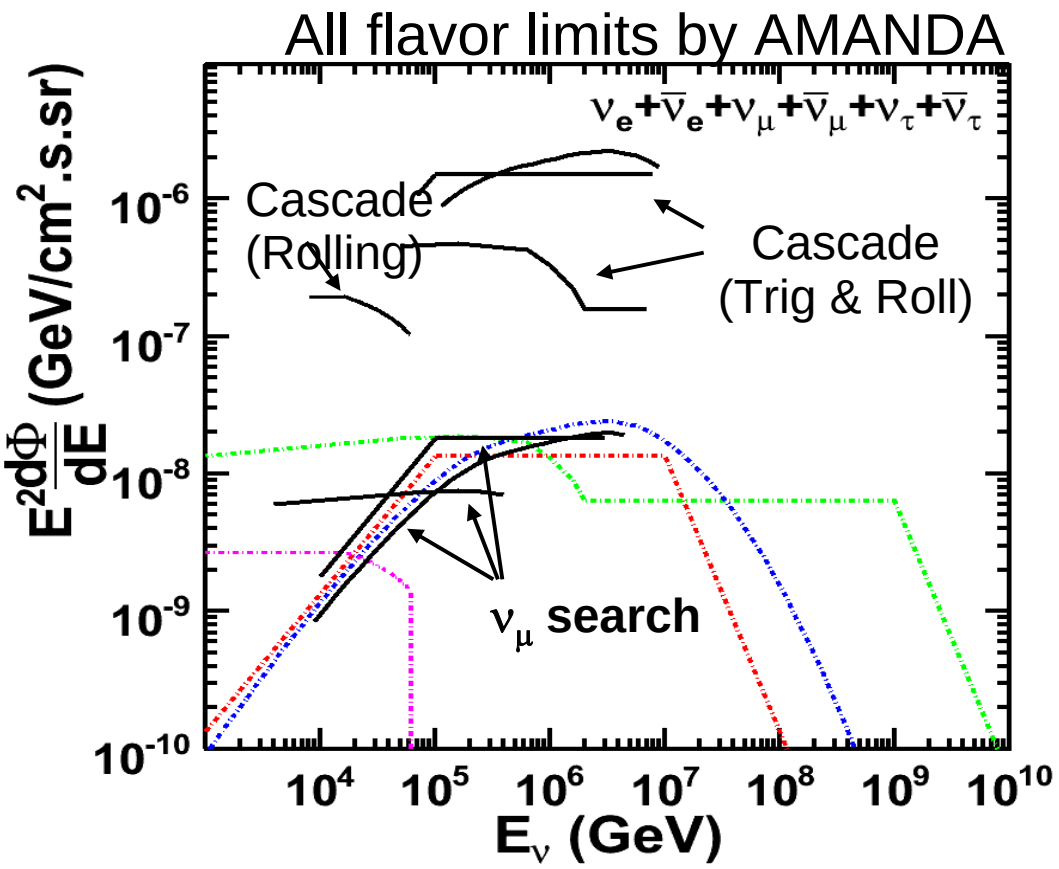
ıbe

I Satellites
E, Swift, etc.)

formation
atellites

GRBs

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



- Look for spatial and temporal coincidences with satellite observations-low background search
- New satellites, swift, GLAST, improve observations
- IceCube will be sensitive to Waxman Bahcall fluxes within 1 year of full detector operation (~70 bursts)!

Diffuse astrophysical neutrinos

When the flux is too low to resolve a point source, you can still see evidence of hadronic acceleration.

Astrophysical neutrino energy spectrum has different energy profile form atmospheric nu's.

Use number of hit channels, Nch, to approximate energy distribution.

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TIFF (Uncompressed) decompressor
are needed to see this picture.

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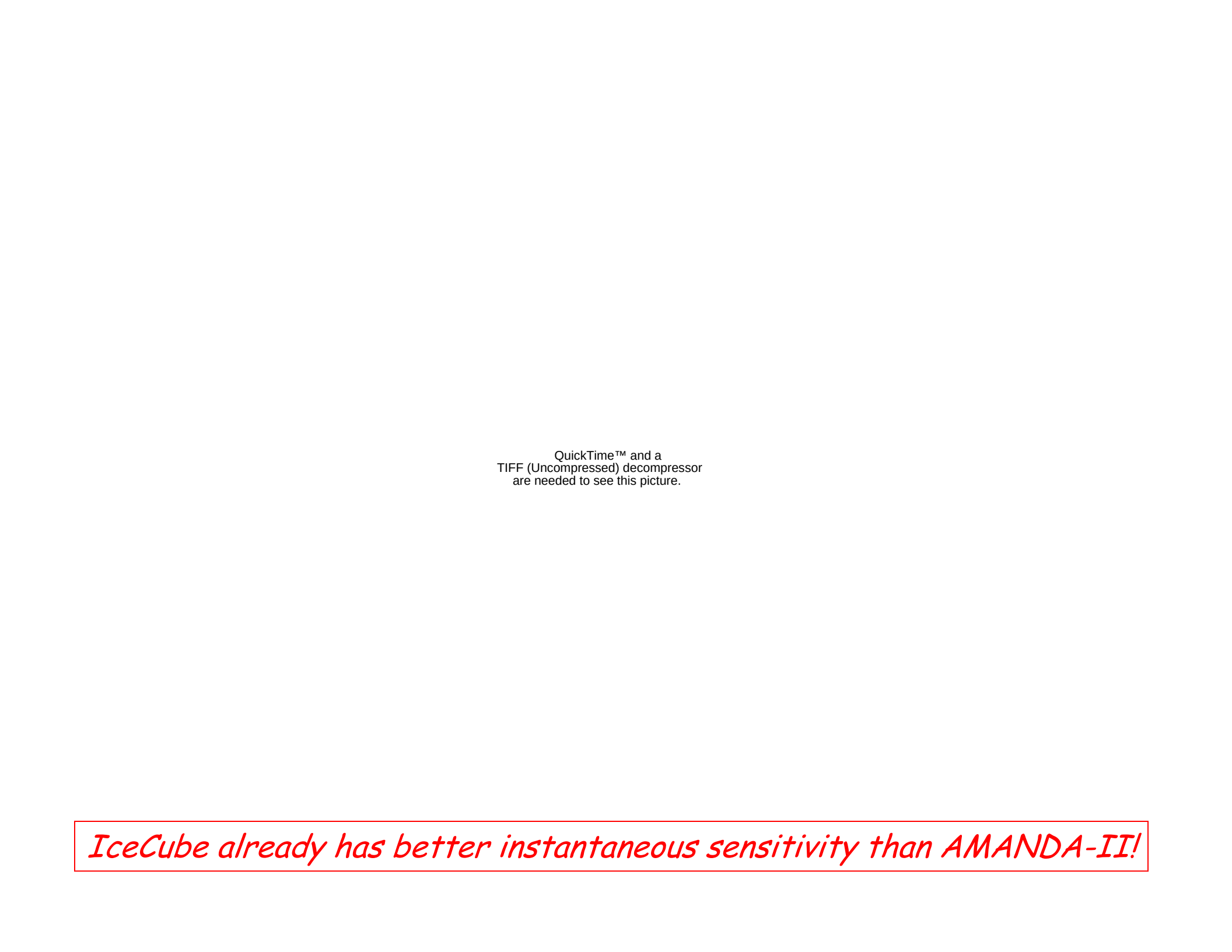
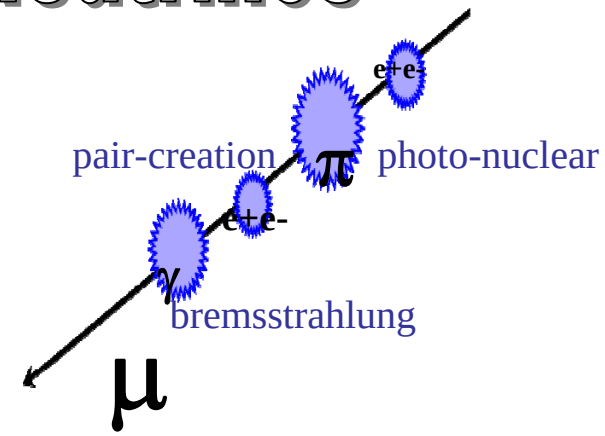


IceCube already has better instantaneous sensitivity than AMANDA-II!

Ultra High Energy Diffuse Neutrinos

•Earth becomes opaque to neutrinos at high energies- look to the horizon

•Very bright!- due to stochastic processes- cut hard on energy related variables.



AMANDA II

a UHE event in IceCube

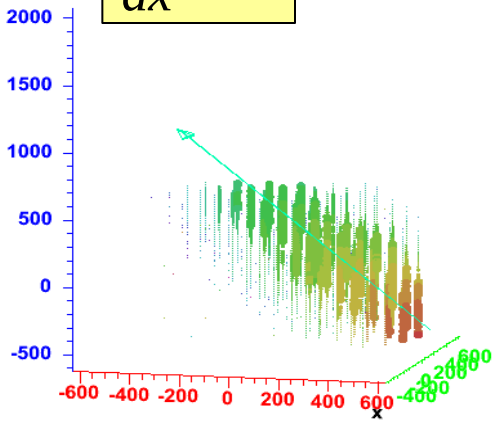
$$\frac{dE}{dx} \propto E$$

9 EeV

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

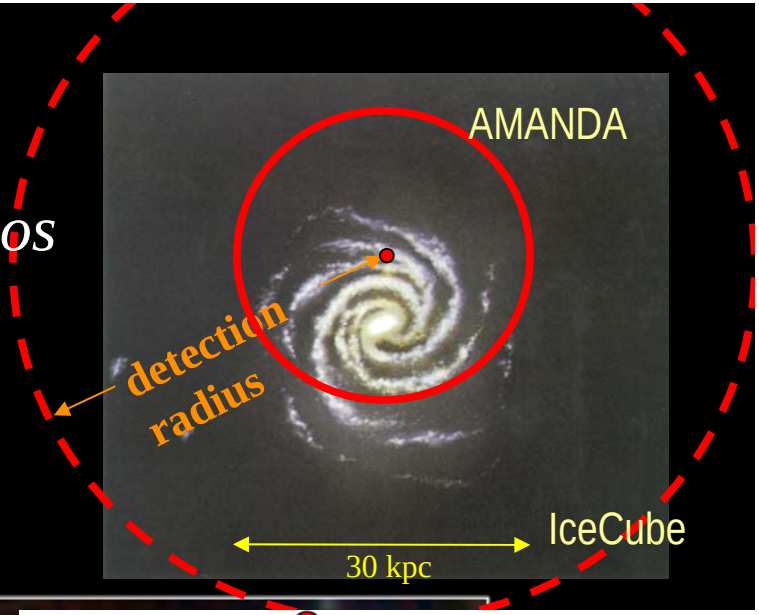
other AMANDA diffuse search

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.



Supernova detection

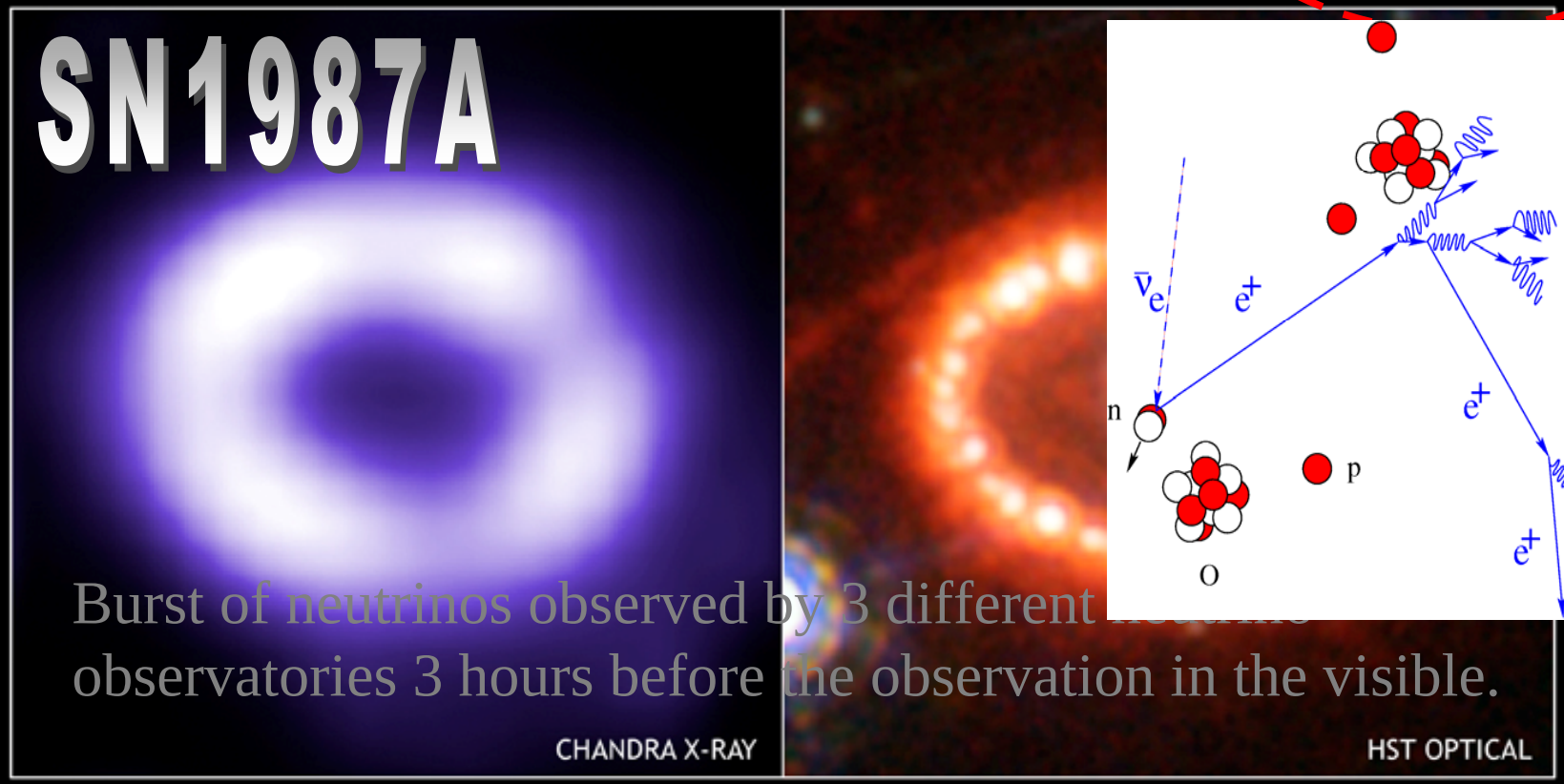
Expect a burst of low energy (MeV) neutrinos from core collapse of supernovae.



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

Detection via increase in "dark noise" rate-low noise PMTs (300Hz) enhance IceCube's sensitivity.

SN1987A



Burst of neutrinos observed by 3 different neutrino observatories 3 hours before the observation in the visible.

Particle physics with IceCube

Too many topics to cover here- many new techniques under investigation

- Neutrino properties
- Atmospheric neutrinos
- Violation of equivalence principle (VEP) , violation of lorentz invariance (VLI)
- WIMPs
- Monopoles, Exotica

Particle physics with IceCube

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- Monopoles, Exotica

Magnetic monopoles

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

- Look for relativistic monopoles above the Cerenkov threshold (>0.75c for direct monopoles, >0.52c for delta electrons)
- Extremely bright events-8000 times brighter than a muon
- Allows a search for downgoing as well as upgoing monopoles
- Accelerated by large scale magnetic fields
- Mass related to GUT scale-Relativistic for $m<10^{14}$ GeV

Relativistic monopoles

Down-going valid for $m>10^8$ GeV

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Upgoing valid for $m>10^{11}$ GeV

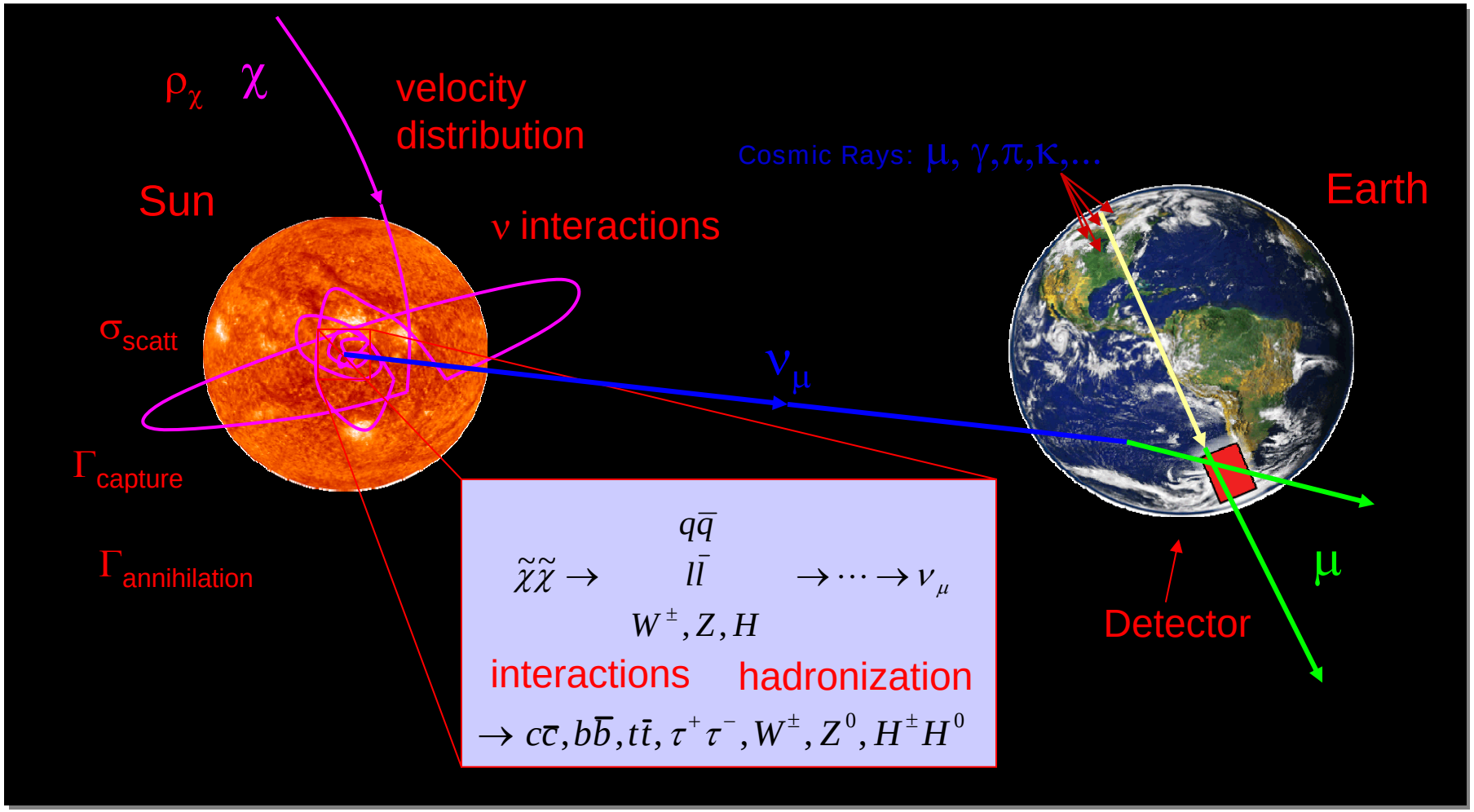
IceCube relativistic monopole limit will supercede the best AMANDA limit with only 9 strings!

Subrelativistic exotics

IceCube sensitivity to slow moving particles is presently limited by a trigger threshold of 8 hit DOM is 5 μs- but investigation into a more sophisticated trigger requirement are underway.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

WIMPs (weakly interacting massive particles)



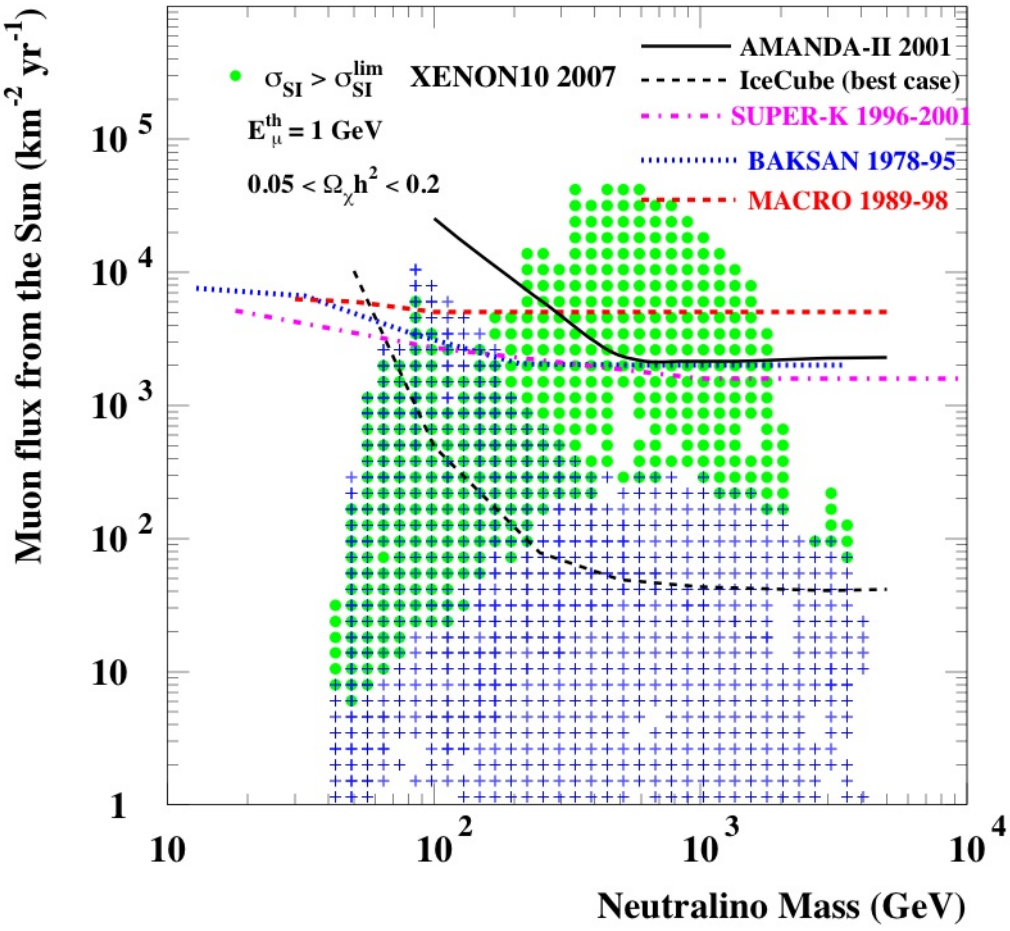
The Sun sinks maximally 23° below the horizon at the south pole

Horizontal events very important!

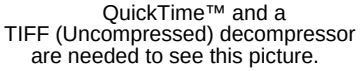
Also look for Wimps trapped in the gravity well of the earth. They will appear to come from the center of the earth.

Solar WIMPs

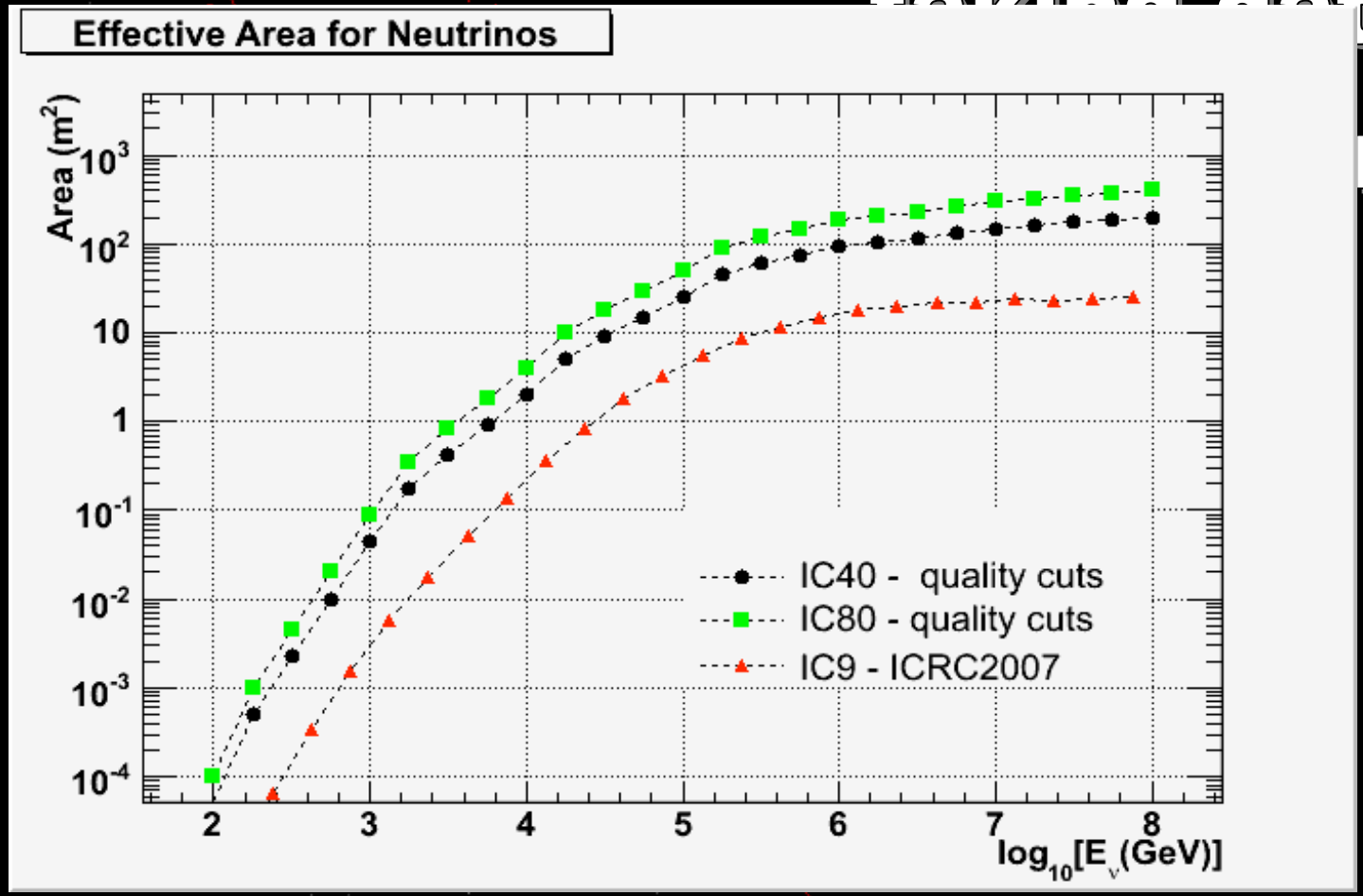
- Look for excess of events over atmospheric expectation coming from the direction of the Sun
- Blind by randomizing in azimuth



Earth WIMPs


QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

We are now taking data



ngs!

The Future

- We are already operating the largest neutrino detector in the world.
- Installed strings are immediately operational.
- First analyses (and publication!) already complete, thanks to data filtering at the Pole and subsequent satellite transmission.
- Analysis techniques are continually refined as we gain operational knowledge- improved analysis sensitivity.
- An additional 14-18 strings will be added in austral summer of 07-08.
- 1 cubic kilometer (80 strings) will be instrumented by 2011.
- Efforts are underway to develop the technology to build a GZK scale neutrino detector after IceCube is complete.

01.15.2006