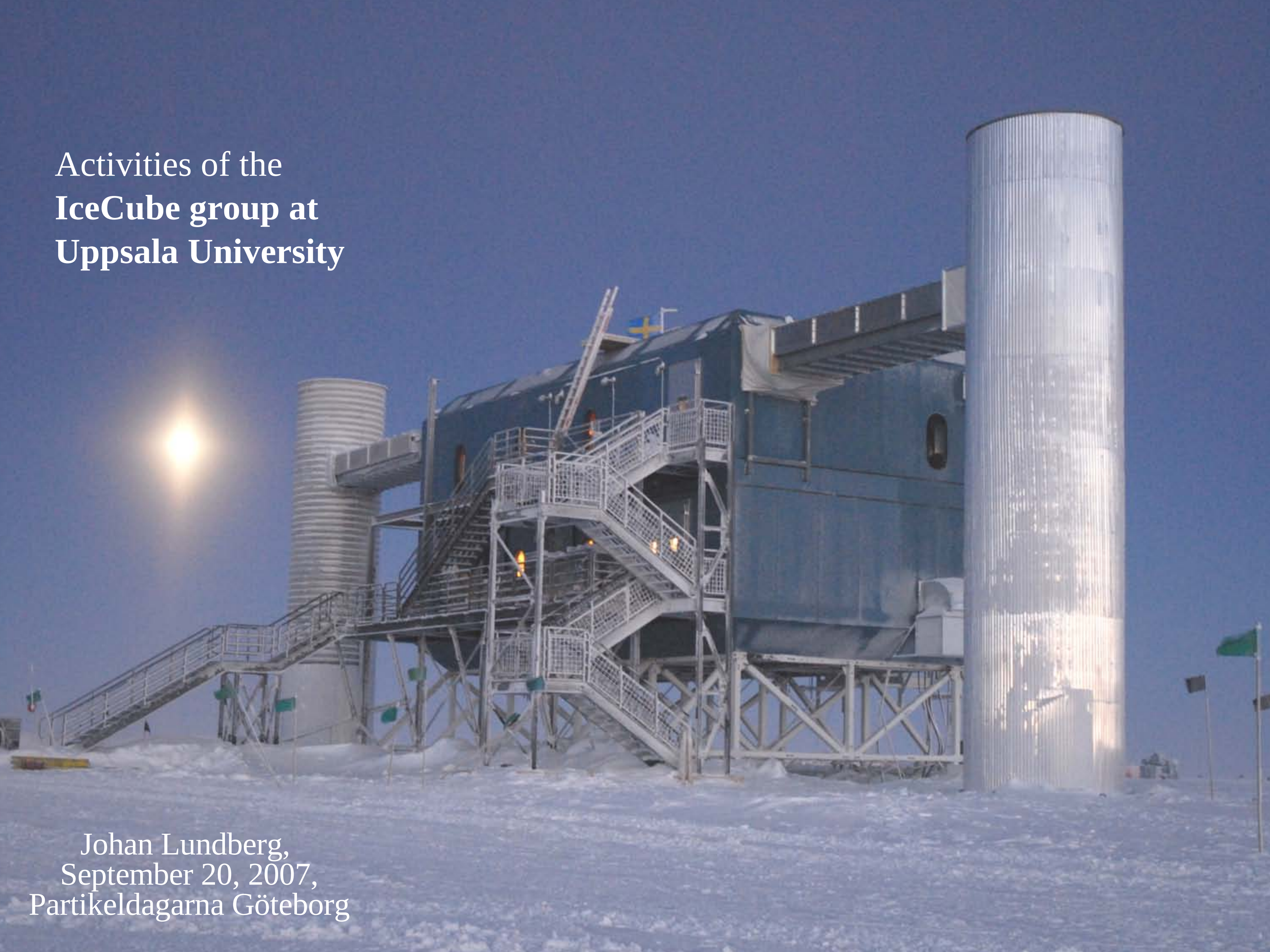


Activities of the
IceCube group at Uppsala University

Johan Lundberg,
September 20, 2007,
Partikeldagarna Göteborg

Activities of the
IceCube group at
Uppsala University

Johan Lundberg,
September 20, 2007,
Partikeldagarna Göteborg

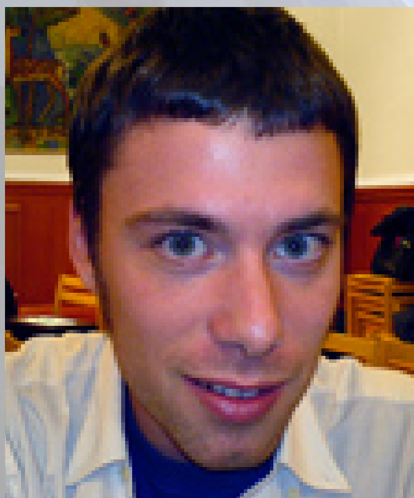
Analysis subjects

Indirect Dark Matter
Neutrino Point Sources
Magnetic Monopoles
Ultra High Energy Neutrinos

Other group activities

Acoustic Neutrino detection
Acceptance Testing of IceCube
DOMs (Digital Optical Modules)
Detector Simulations
Photon tracking for the
South Pole Ice
IceCube Geometry Calibration
Trigger development

New Members



Olle

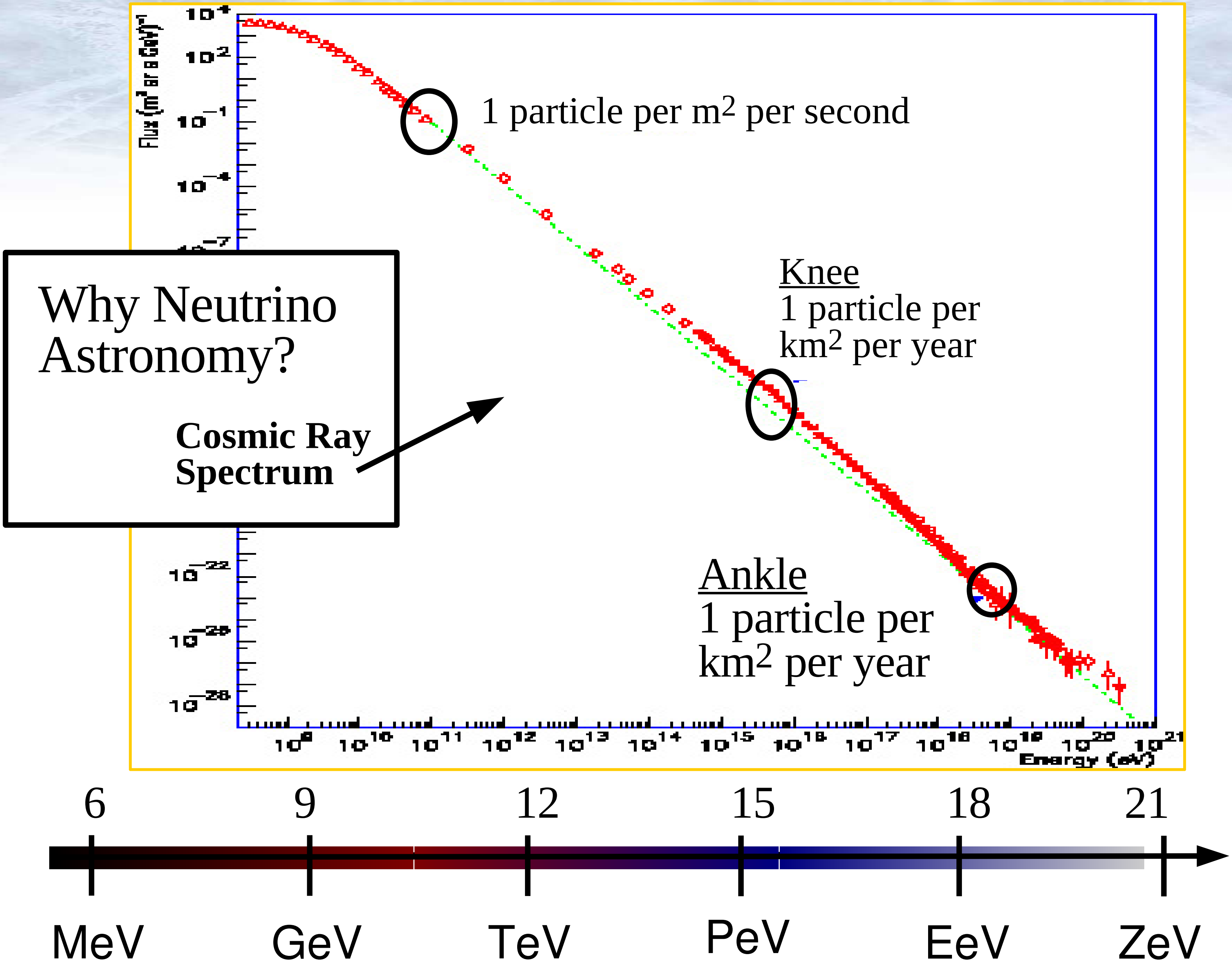
Martino

Uppsala

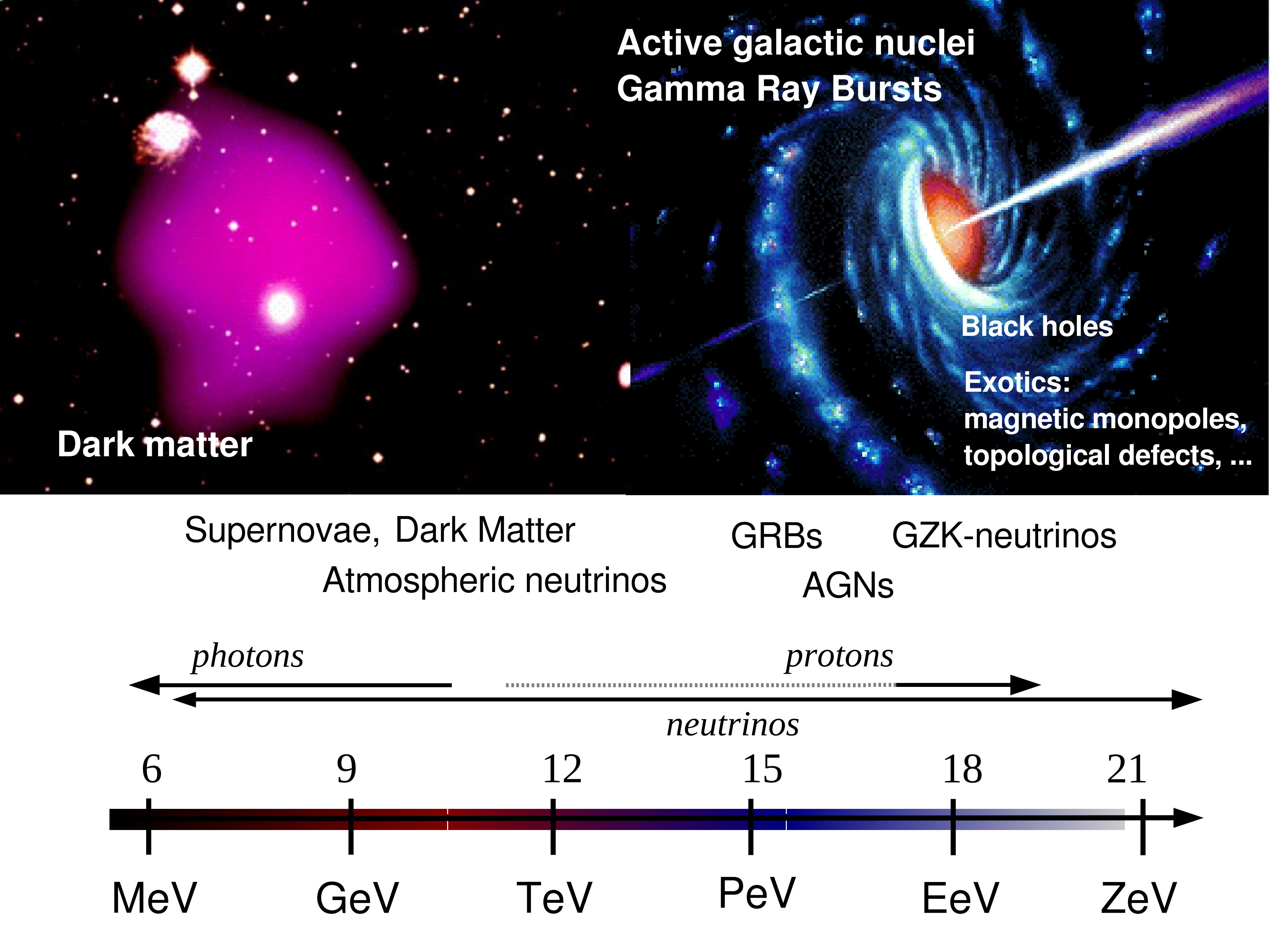
Olga Botner
Allan Hallgren
Carlos P. de los Heros

PhD students:

Olle Engdegård
Martino Olivo
Johan Lundberg
Arvid Pohl (Kalmar)

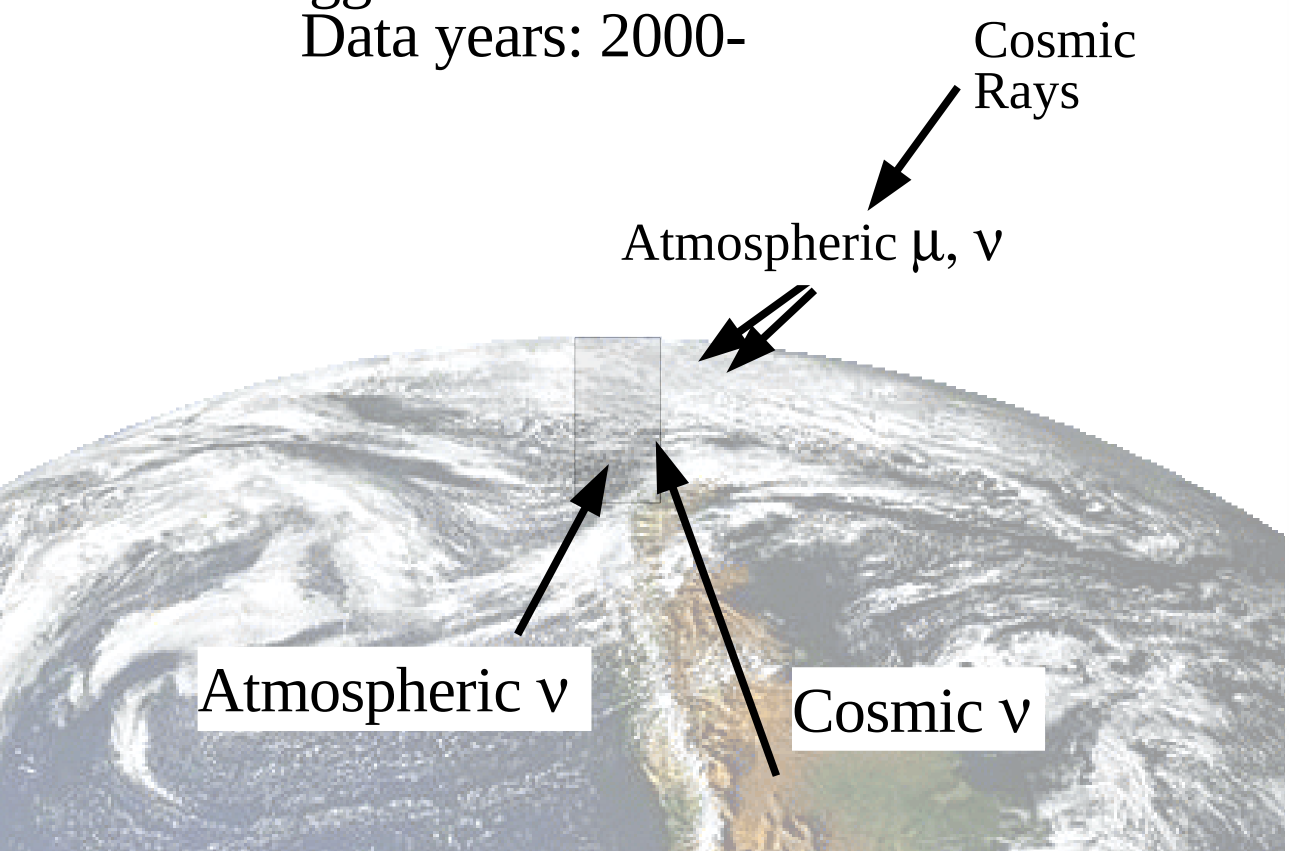


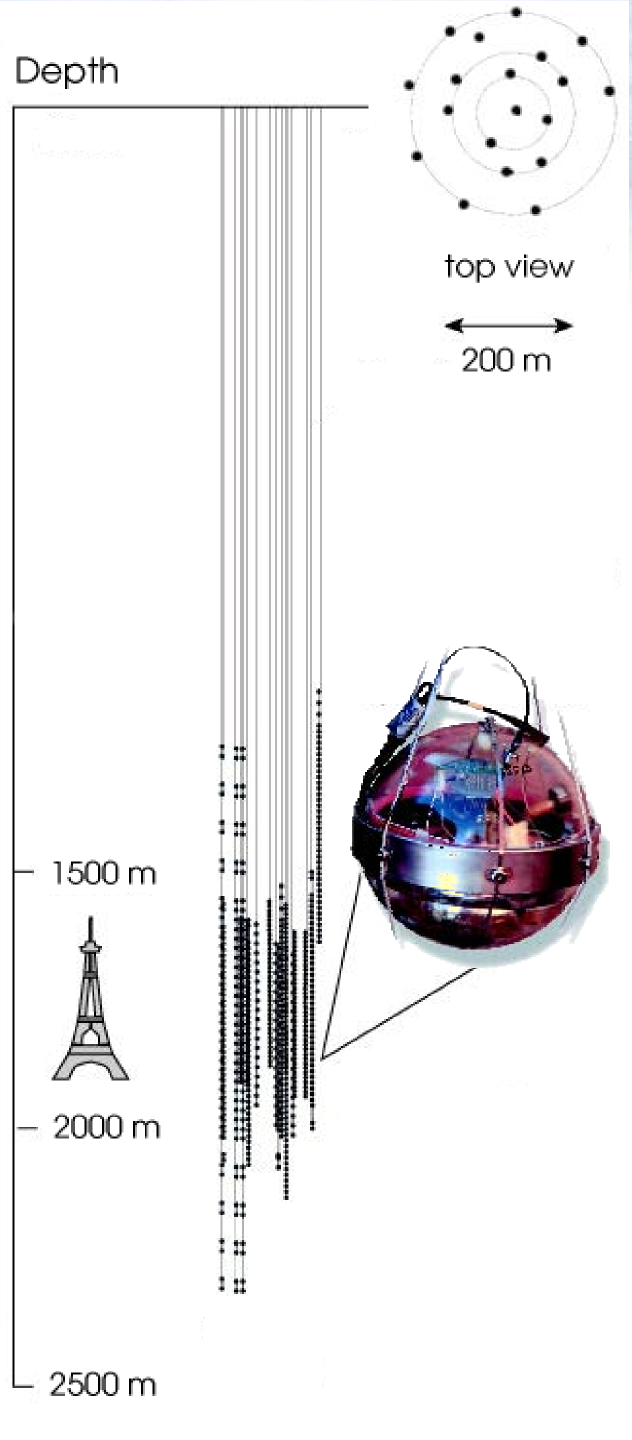
Why Neutrino Astronomy?
Cosmic Ray Spectrum
1 particle per m2 per second
Knee
1 particle per km2 per year
Ankle
1 particle per km2 per year
Energy (eV)
6
9
12
15
18
21
MeV
GeV
TeV
PeV
EeV
ZeV


Active galactic nuclei
Gamma Ray Bursts
Black holes
Exotics:
magnetic monopoles,
topological defects, ...
Dark matter
Supernovae, Dark Matter
Atmospheric neutrinos
GRBs
AGNs
GZK-neutrinos
photons
protons
neutrinos
6
9
12
15
18
21
MeV
GeV
TeV
PeV
EeV
ZeV

Neutrino Astronomy

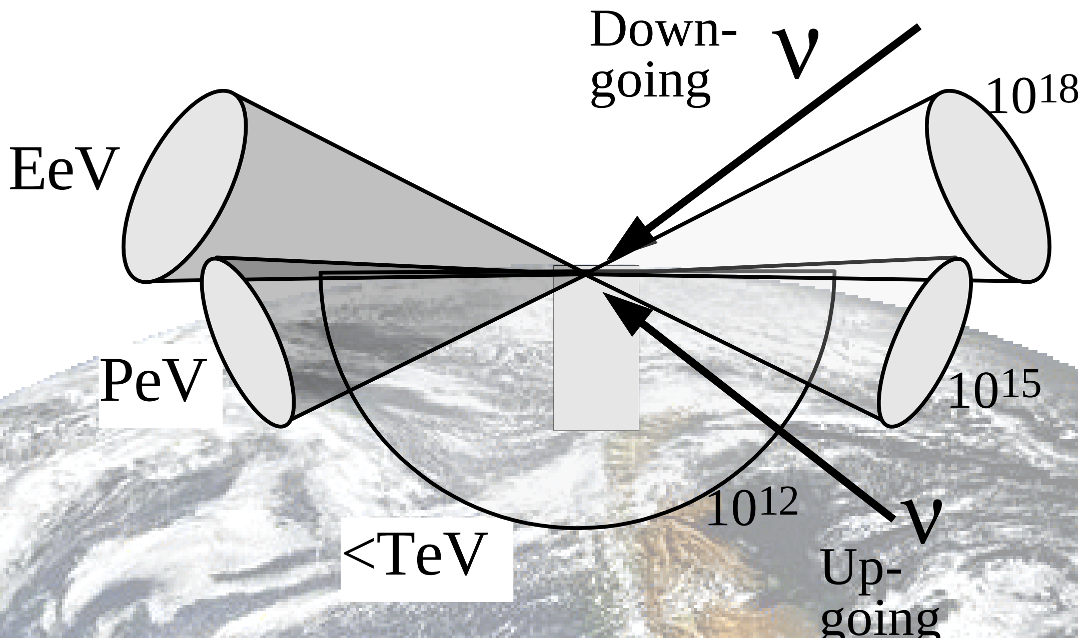
AMANDA-II
19 strings
677 OMs
Trigger rate: 100 Hz
Data years: 2000-





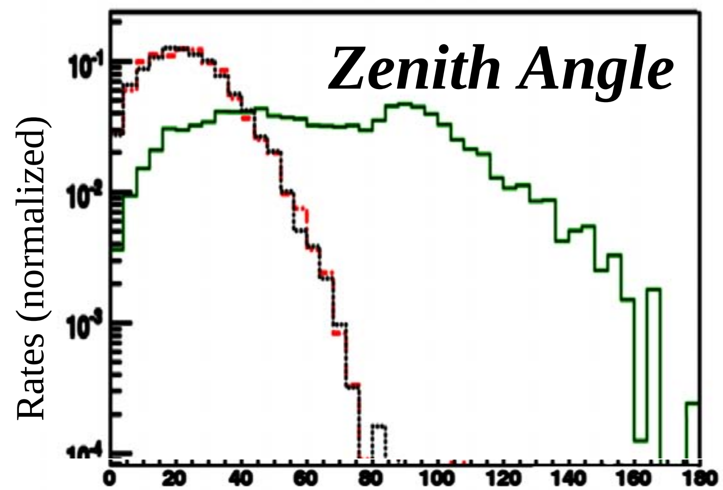
Searching for UHE neutrinos

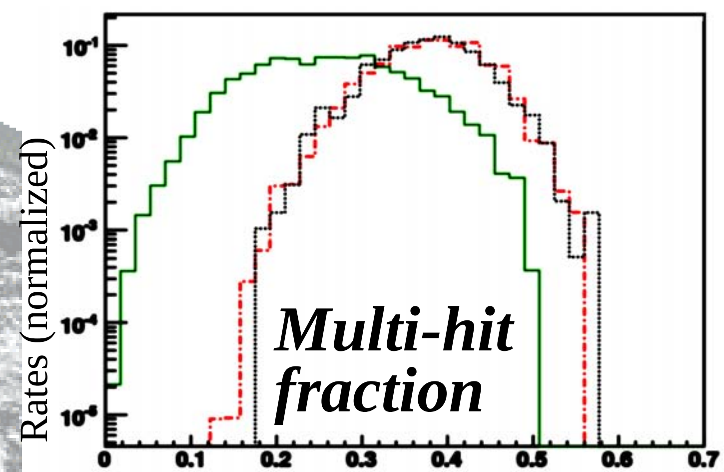
- Atmospheric neutrinos no major BG
- Energies >PeV ν absorbed in the Earth
- Study tracks from horizontal neutrinos



Analysis variables
examples

Signal MC: Diffuse E^{-2} υ flux
BG-MC: Corsika Atm-μ flux
Small Amanda-II Data Sample





Amanda Results

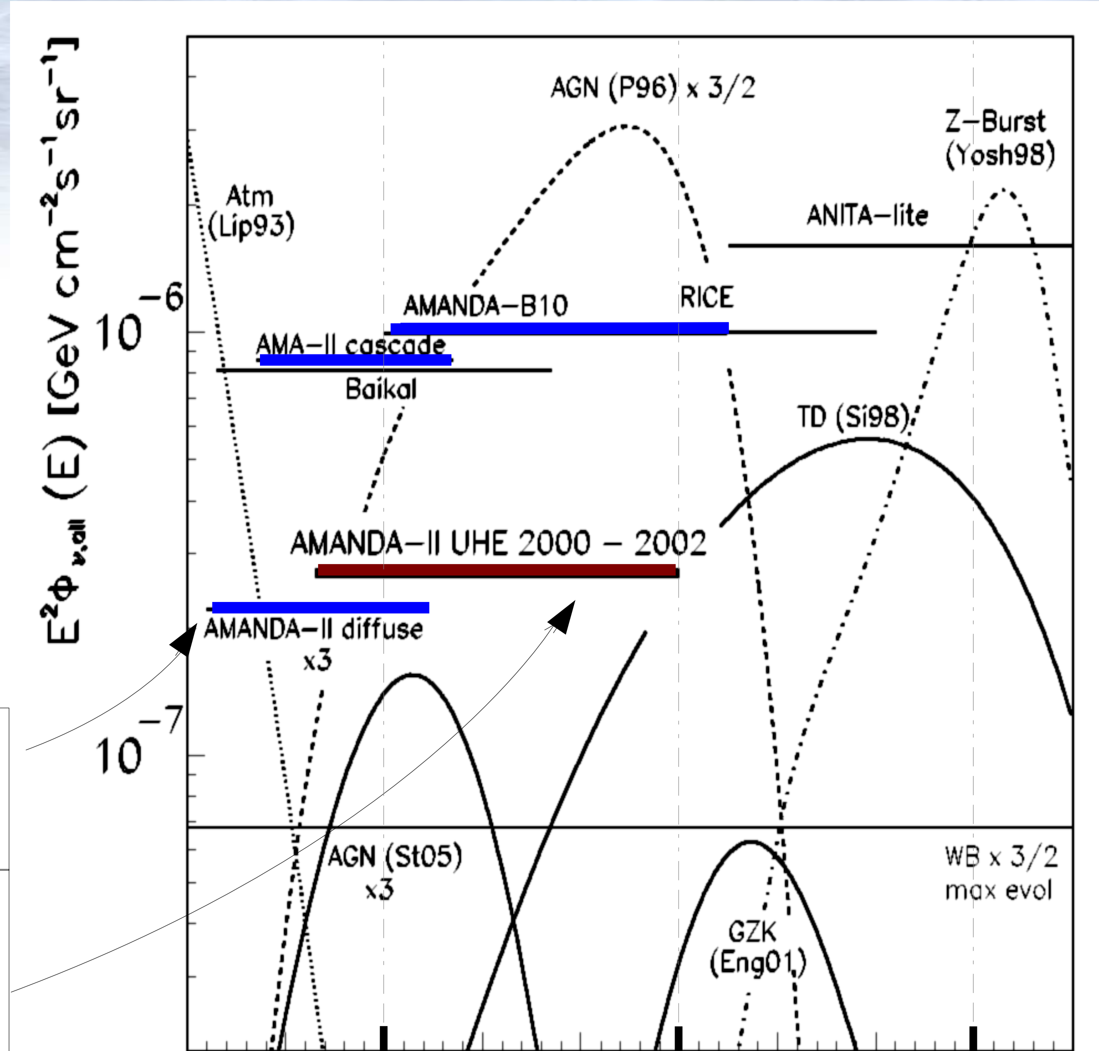
Good data since year 2000
~69 ref journal papers
~260 conference proceeding
48 PhD thesis
40 Amanda/IceCube
papers at ICRC-2007

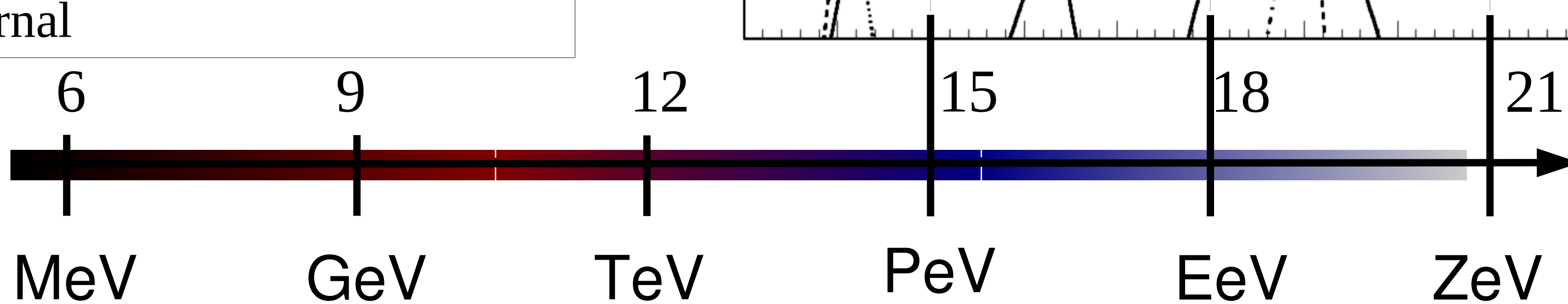
Subjects:
Time variable sources (GRBs, SN), DM, Monopoles, Stacked Sources, Total diffuse UHE flux limits

AMANDA-II 2000-2002

Phys. Rev. D 76, 042008 (2007)

AMANDA-II UHE 2000-2002 just submitted to Astrophysical Journal

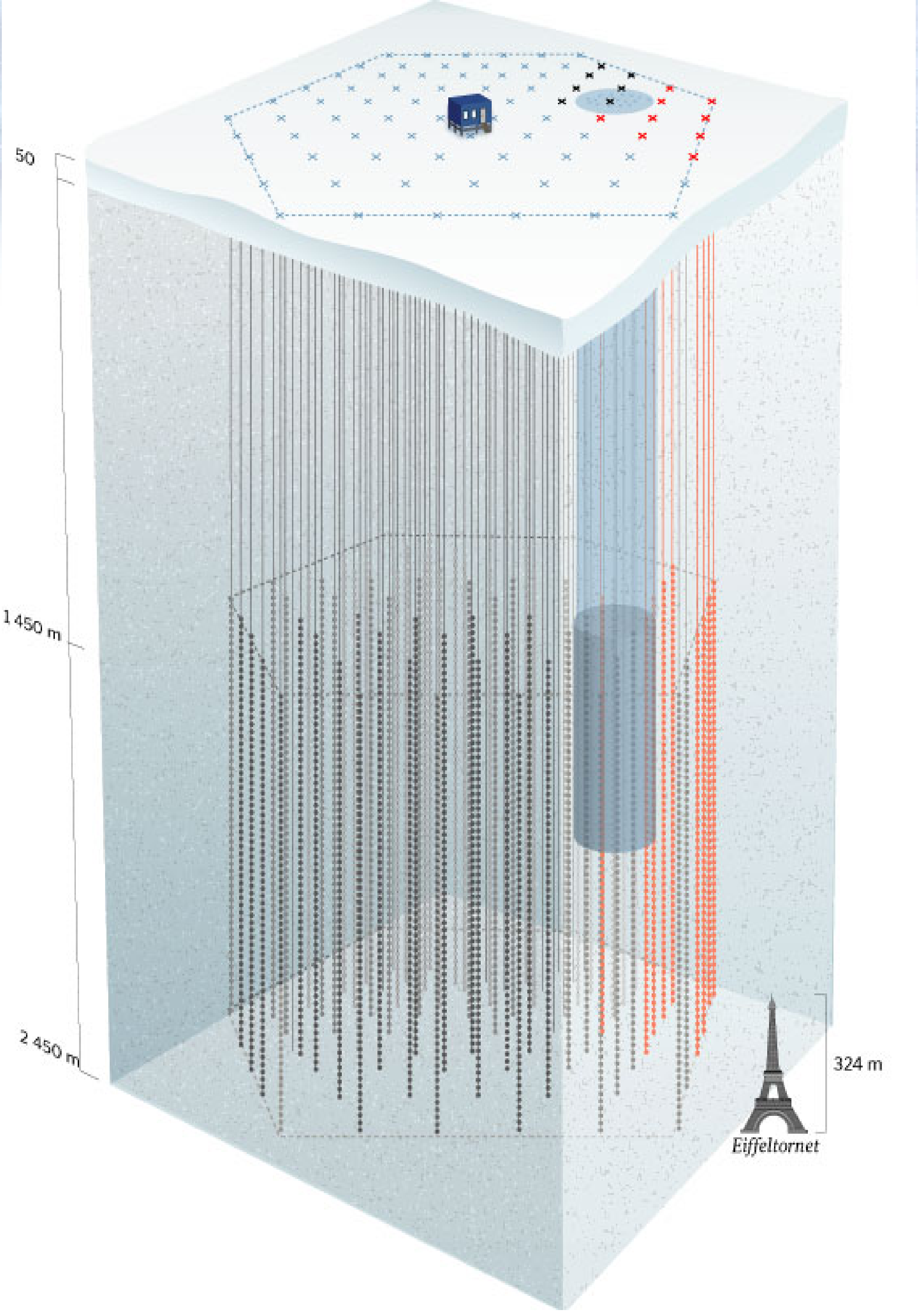




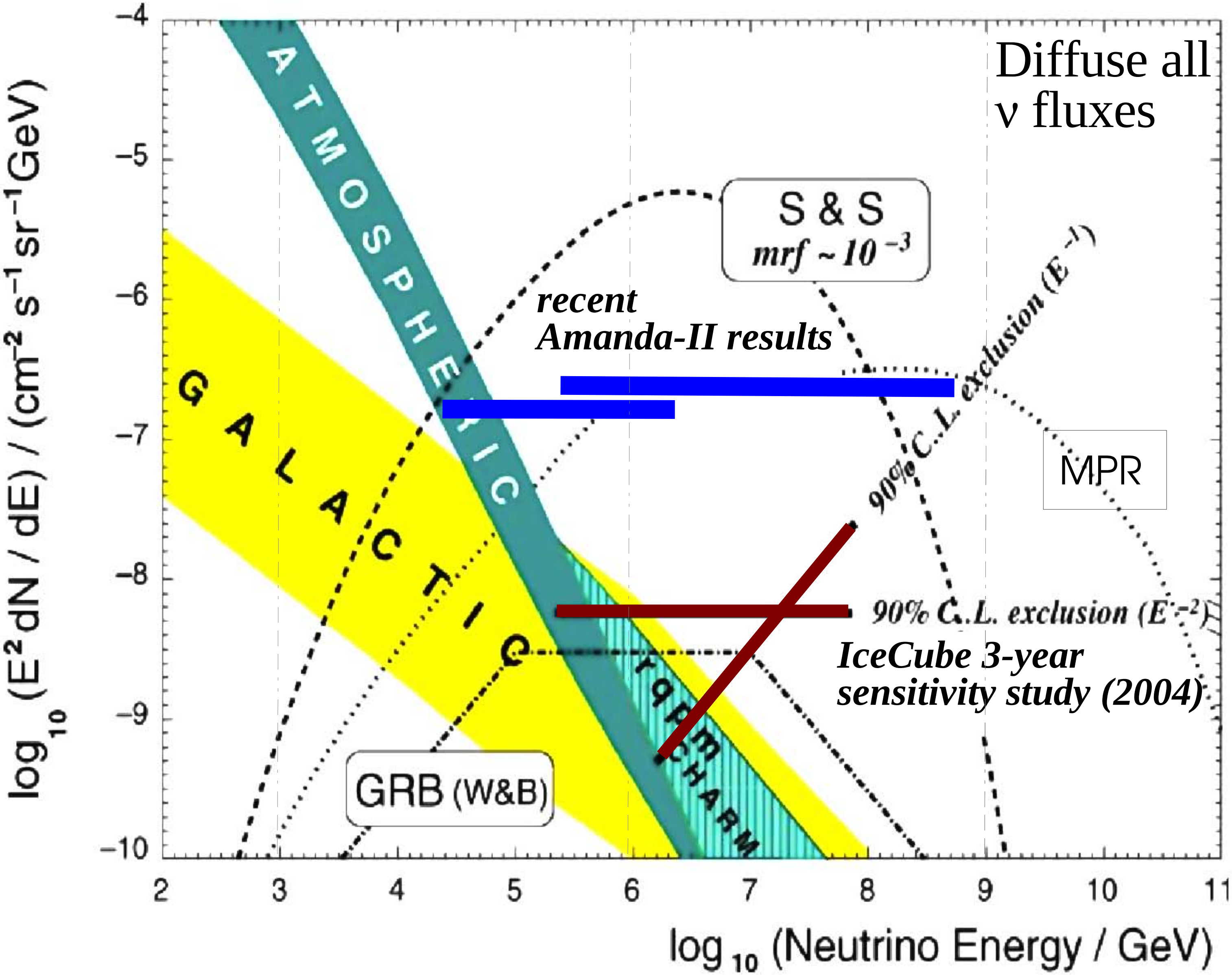
IceCube status

IceCube-22

- 22 strings run since May 23, 2007
- 98.5% of deployed DOMs are in use
- ~96% live time
- Event rate ~600 Hz
- More than one billion events recorded so far

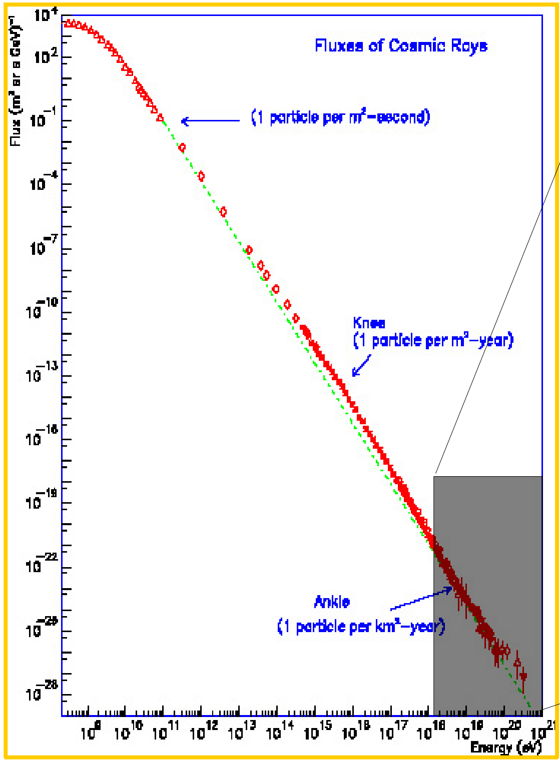


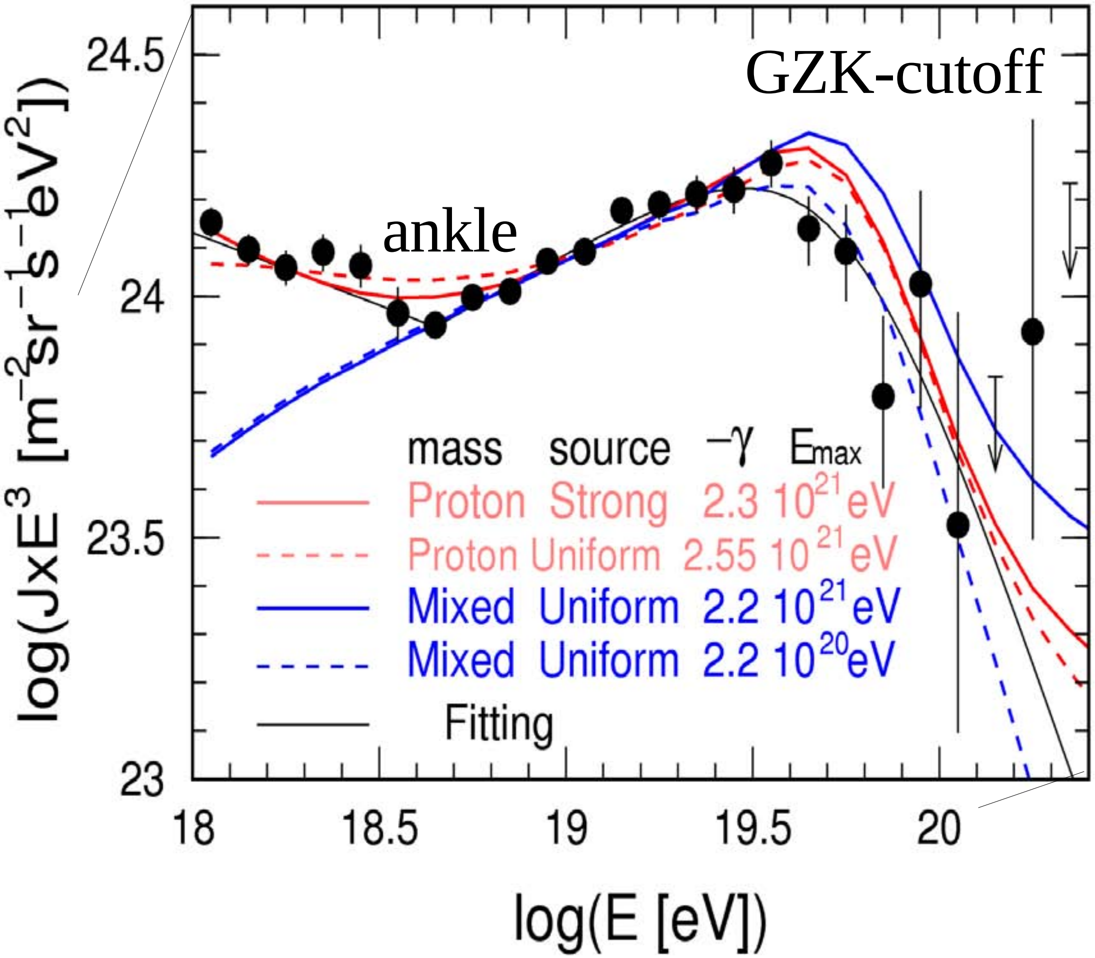
IceCube compared to Amanda



Cosmic Rays again

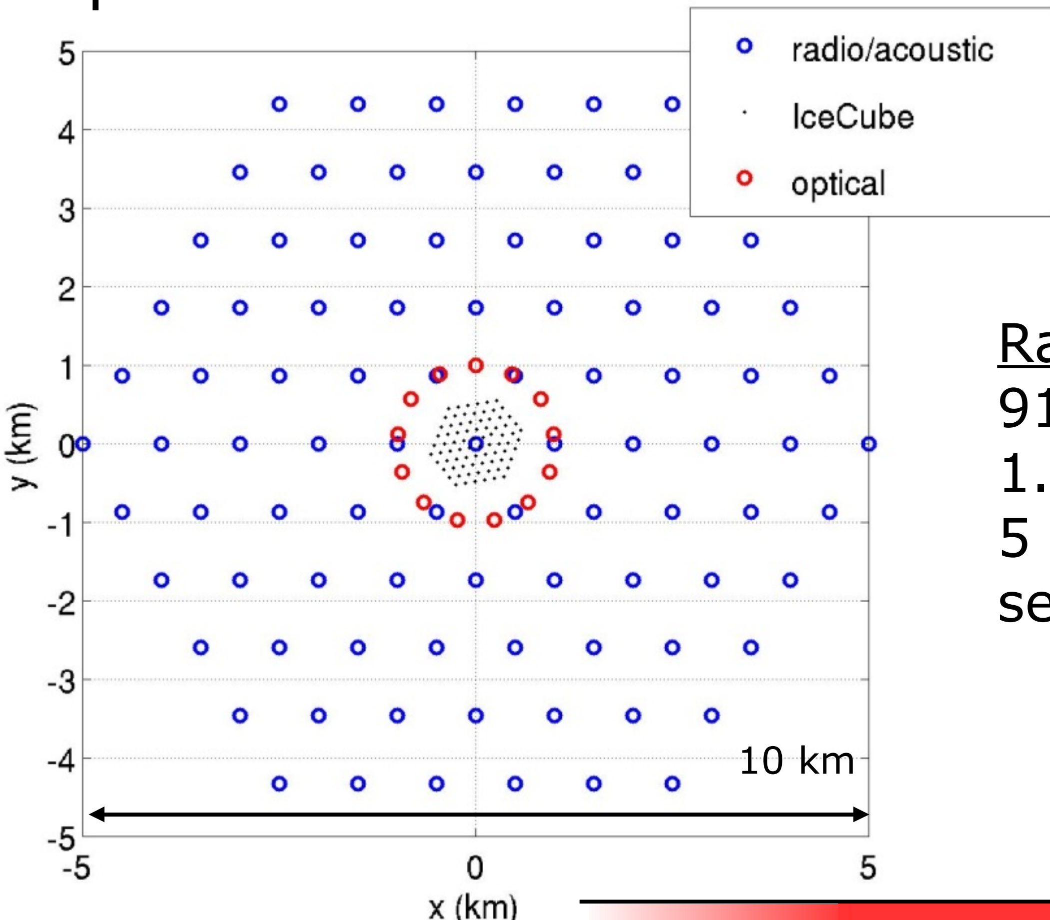
UHECR spectum, ICRC-2007
Pierre Auger Observatory





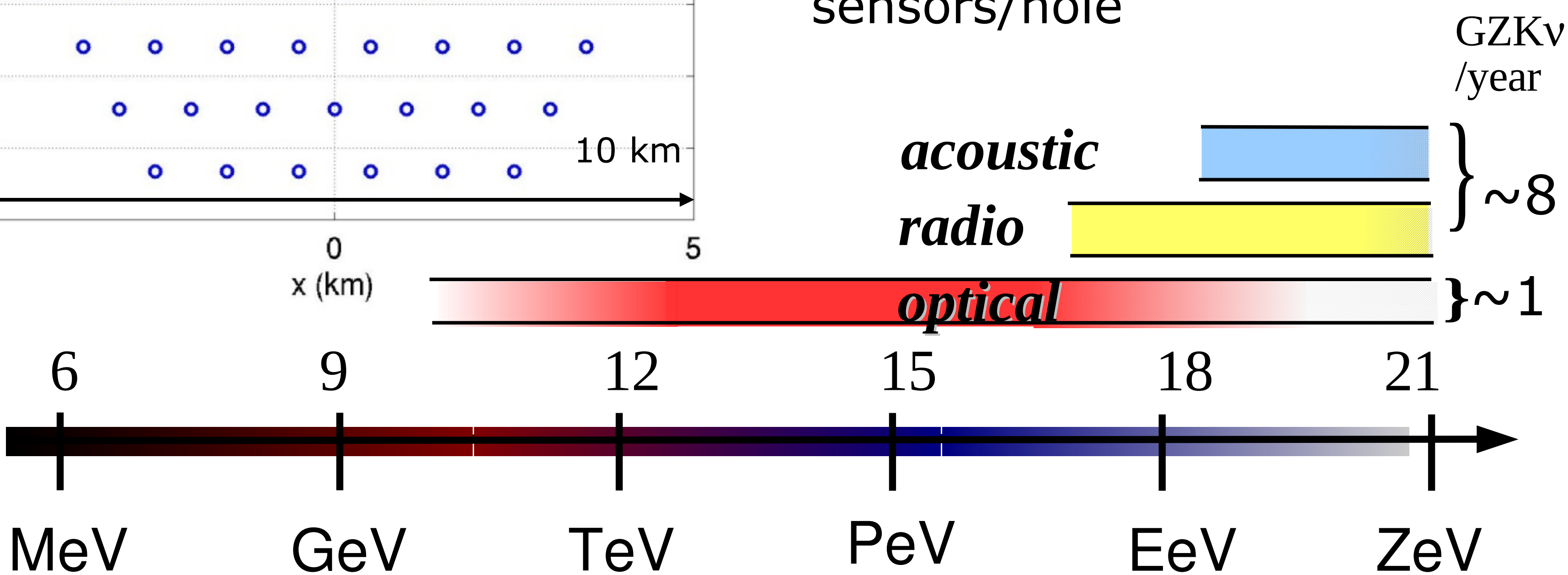
How can GZK neutrinos be observed?

Prospects for GZK ν detection with optical-radio-acoustic detectors



Optical:
80 IceCube +
13 extra strings
1 km radius, 1.5-2.5 km depth

Radio/Acoustic:
91 holes, 1 km spacing,
1.5 km depth
5 radio+300 acoustic sensors/hole



S.P.A.T.S - ***S**outh **P**ole **A**coustic **T**est **S**ystem*

How can we construct these detectors?

Emitter module with Pressure/Temperature Sensor

Transmitter (Ring shaped piezocheramic)

Detector Module

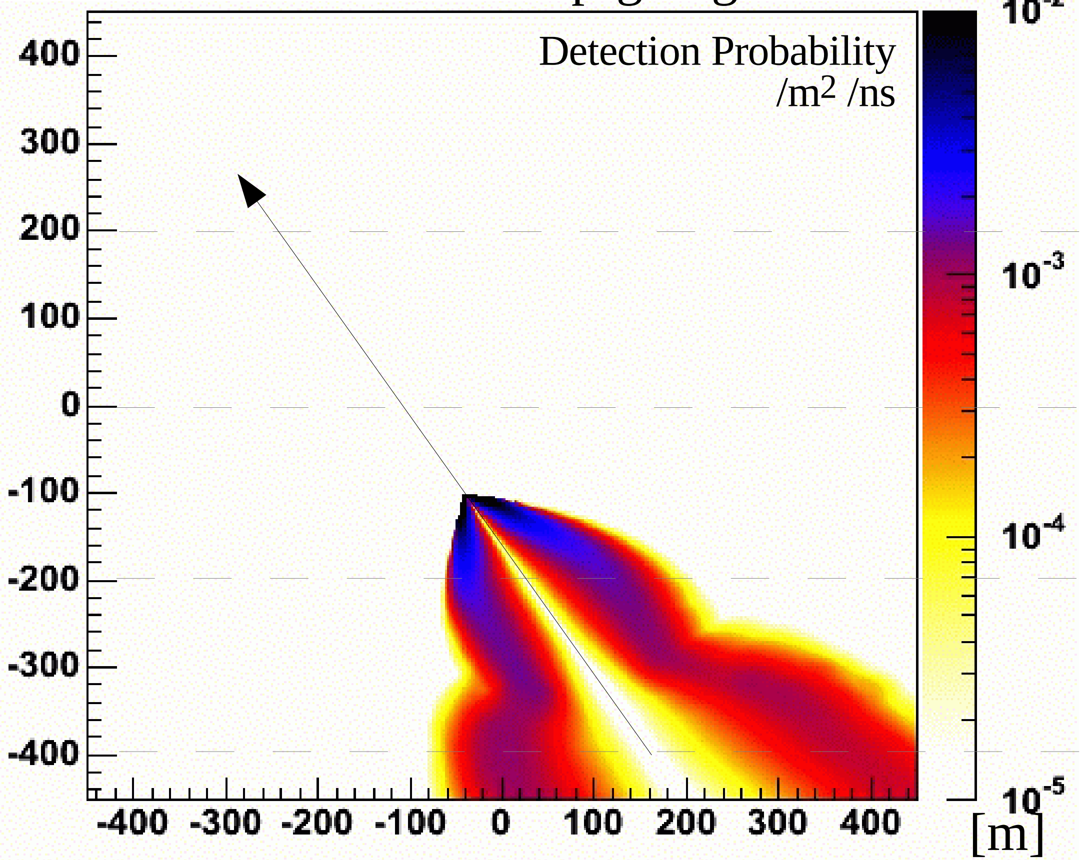
- Sound absorption length in ice?

- Test system was fist tested at Torneträsk
- 3 acoustic test strings deployed in IceCube holes
- 1 more string to be deployed this season

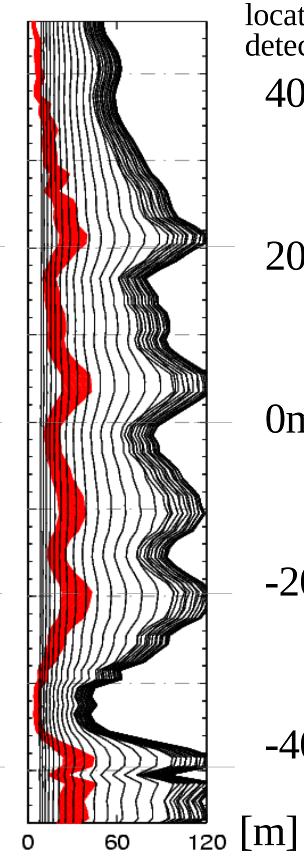
Deployment 2006/2007

Modeling photon transport in natural heterogenous ice
- Photon scattering and absorption.

Space/Time - evolution of photons
Simulation of infinite up-going muon.



Scattering and **Absorption** lengths
at different wavelengths



Light tracking through ice and water
-- Scattering and absorption in heterogeneous media with **Photonics.**
NIM-A In Press. **J Lundberg**, P. Miocinovic, K. Woschnagg, T. Burgess d,
J. Adams, S. Hundertmark, P. Desiati, P. Niessen
http://arxiv.org/abs/astro-ph/0702108

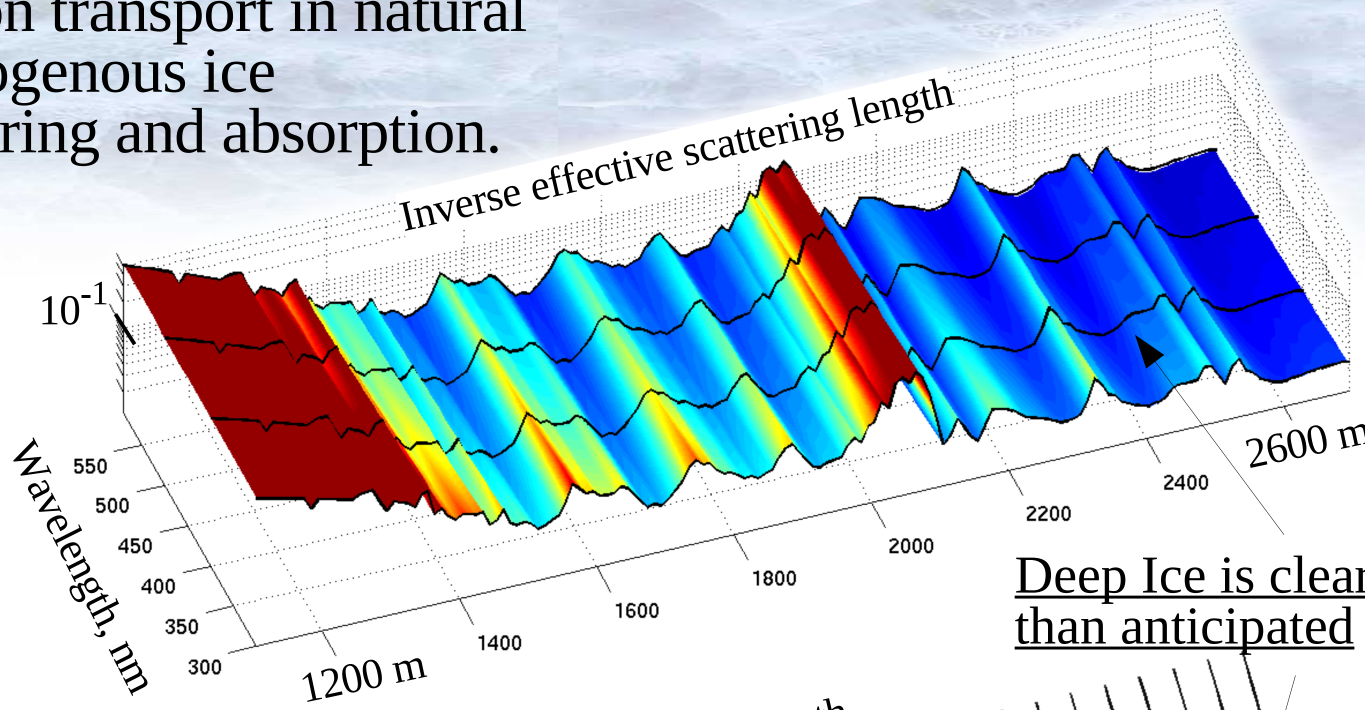
Modeling photon transport in natural heterogenous ice
- Photon scattering and absorption.

The Ice Model

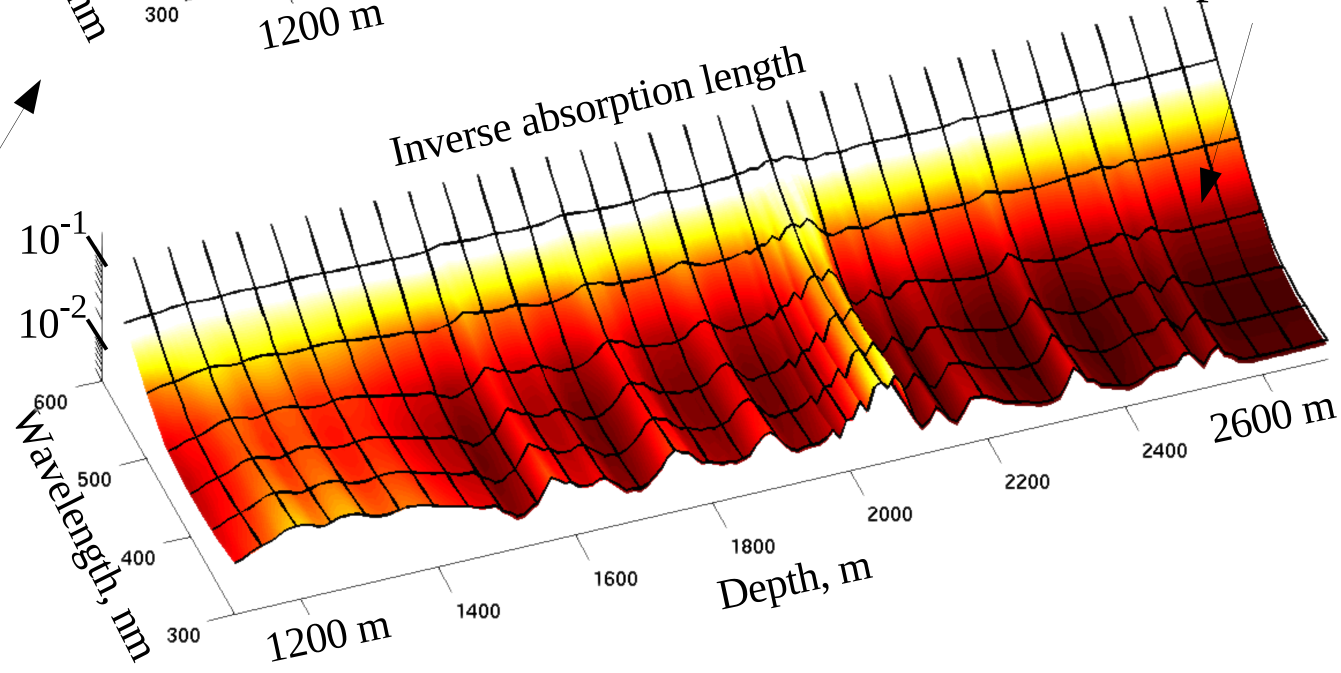
Scattering and absorption as function of depth and wavelength

Fitted to time distributions and fluence data from in-situ calibration sources.

New Ice model with sharper structures



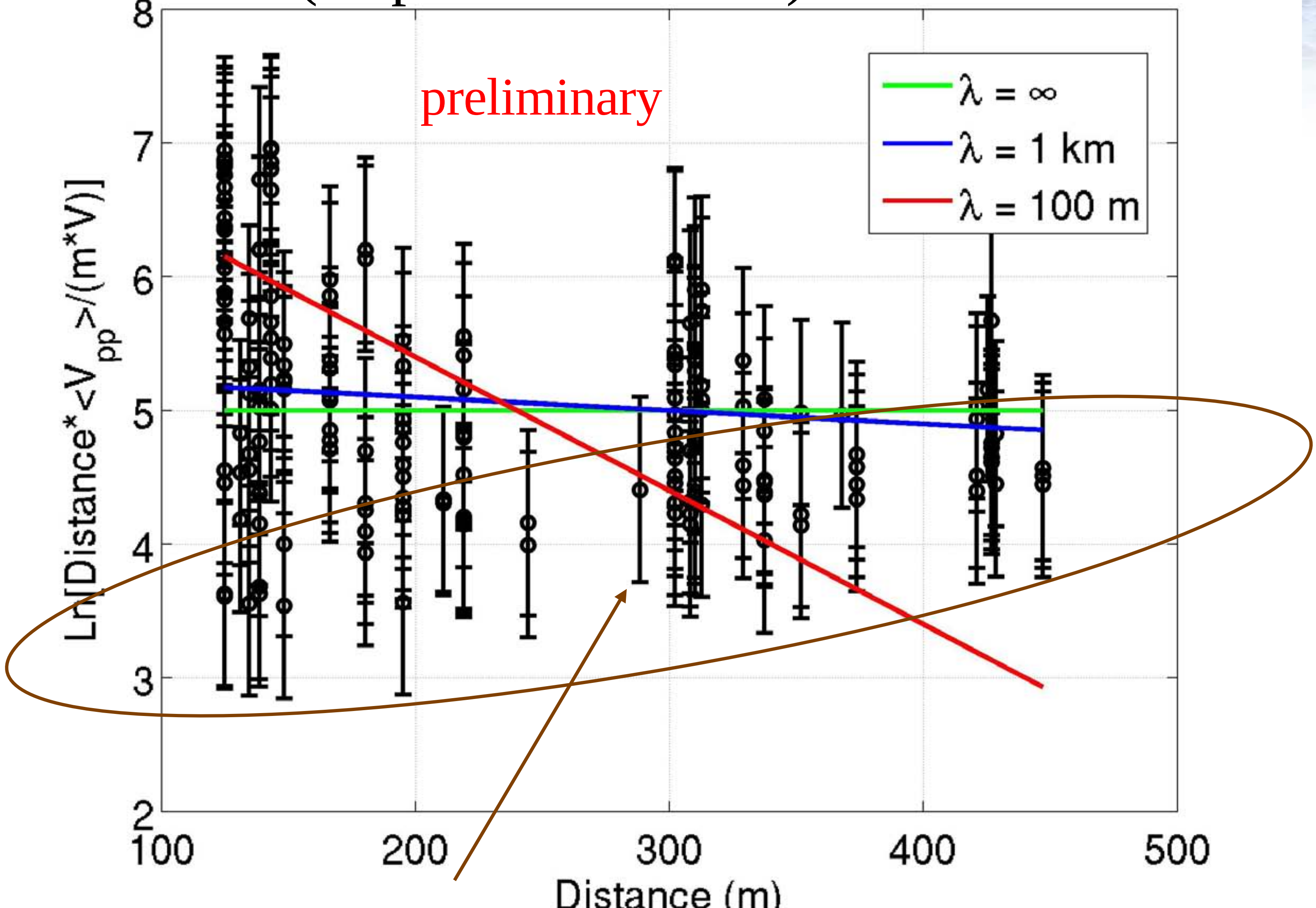
Deep Ice is clearer than anticipated




Work in progress...
Questions?

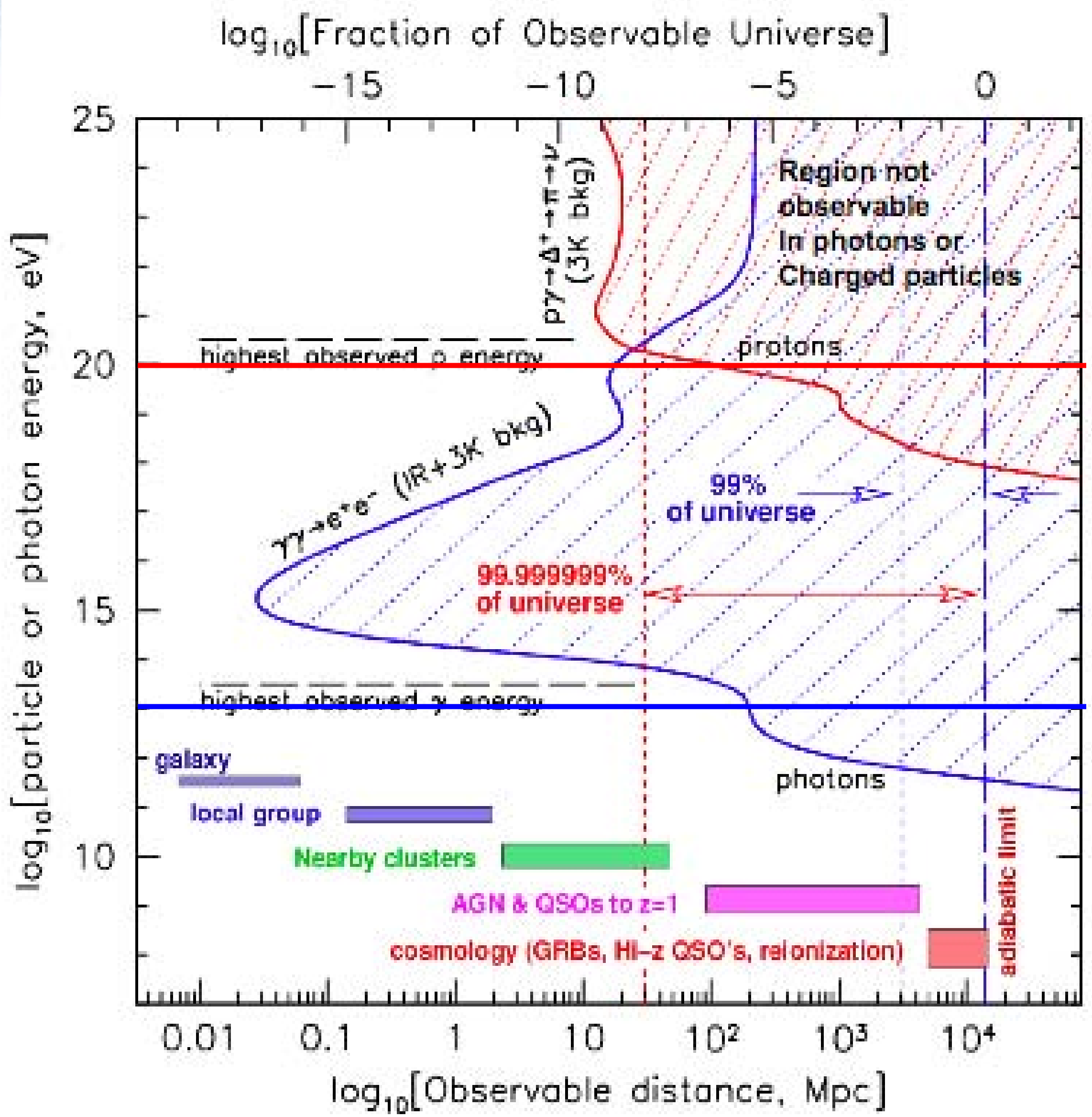
…

Attenuation analysis: work in progress
Ln(amplitude*distance) vs. distance



Missing many pairs in noise: overcome with pulse averaging

Astronomy and particle physics with high energy photons, cosmic rays, and neutrinos

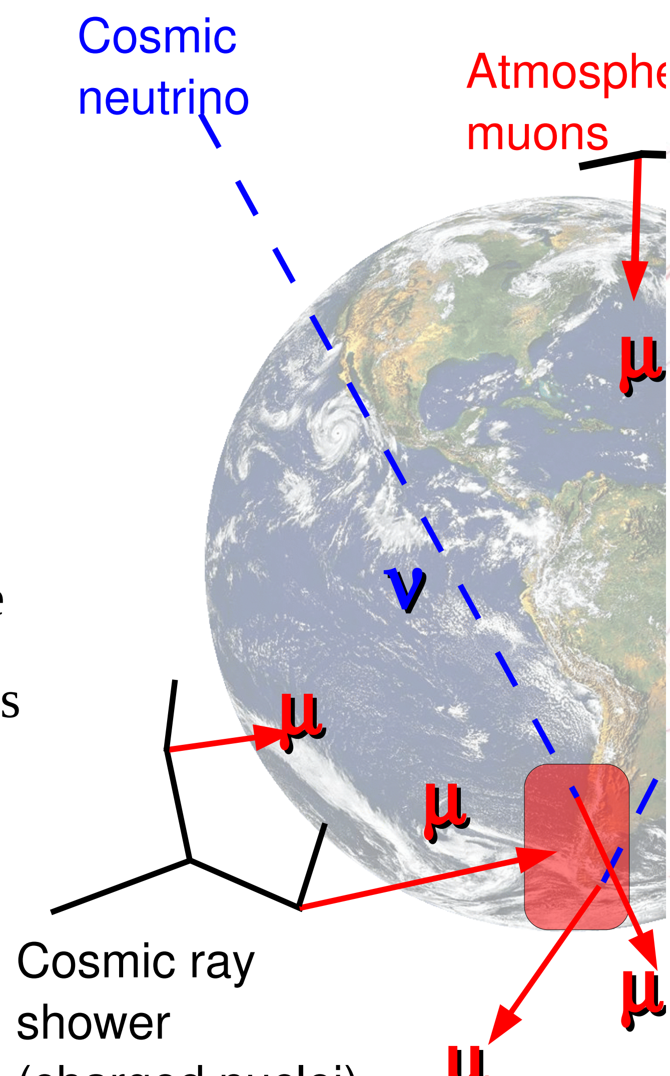


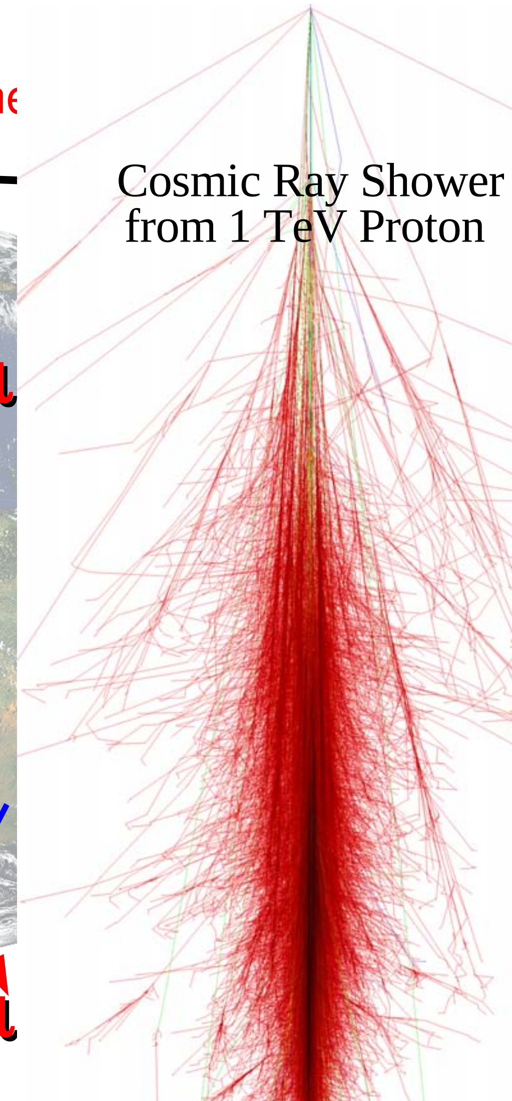
In addition to astronomy, we can study fundamental physics:

Lorentz invariance ($\gamma \approx 10^{11}$!)
quantum gravity
extra dimensions
topological defects
GUT relics

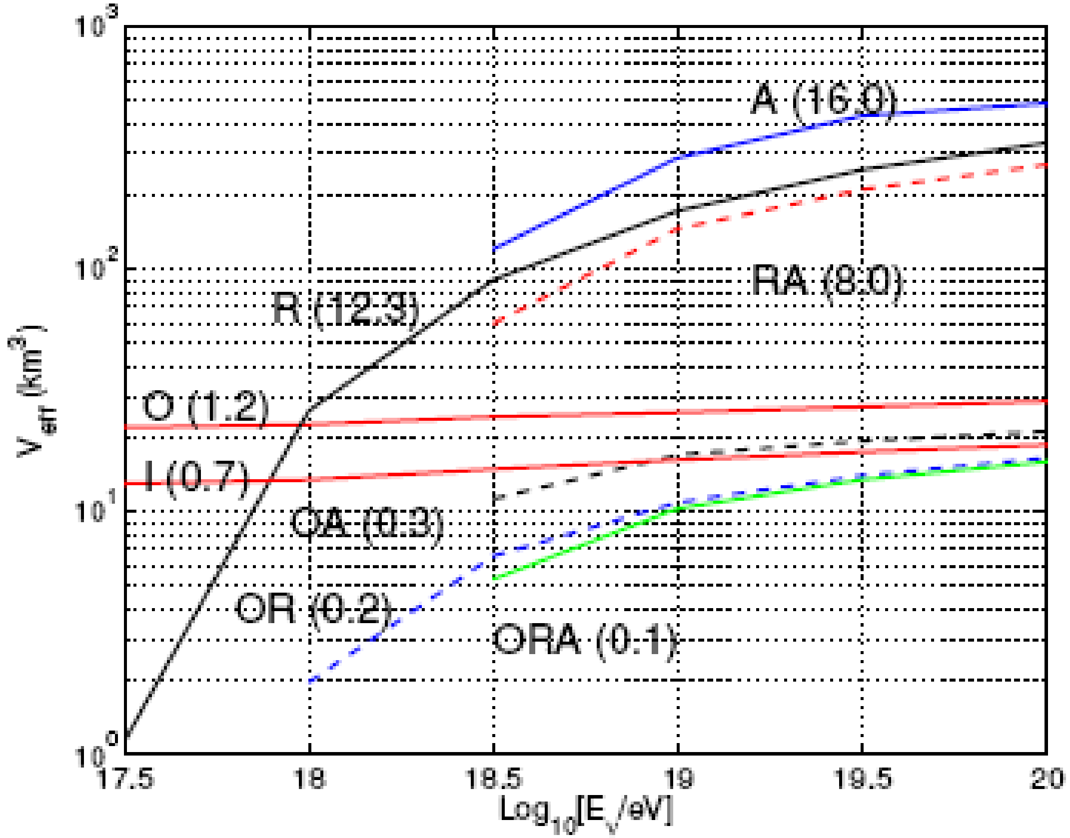
The earth as a muon filter

- Cosmic rays colliding with the atmosphere also creates muons
- These look just like the neutrino muons
- Atmospheric muons outnumber neutrino muons by a factor **10^6**
- Muons have a limited range – by looking down/north the earth is as a muon filter and only neutrino induced muons are studied





Monte Carlo Simulated Combined Array



Detected GZK-neutrinos/year

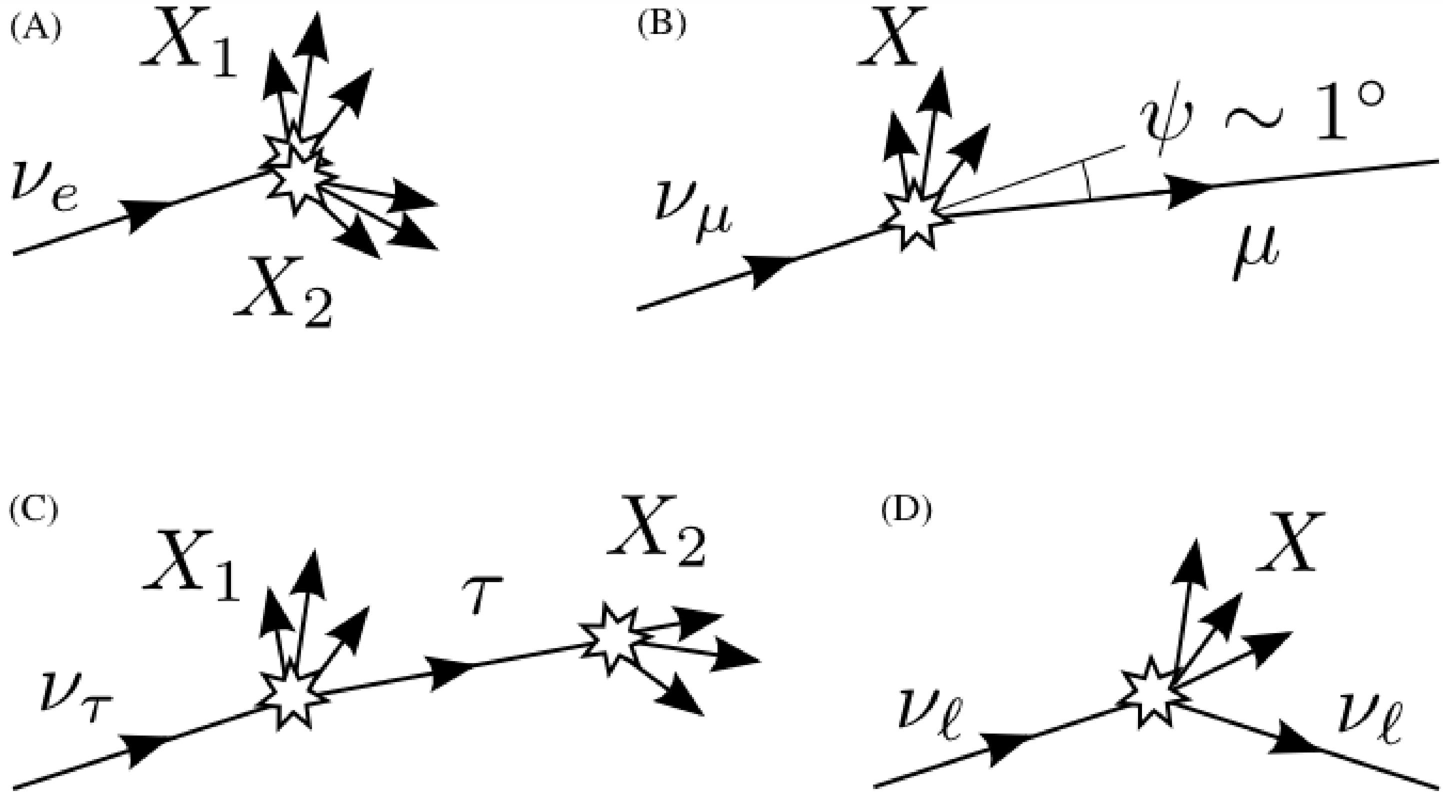
Combination of methods is powerful

icecube;0.7

O: I3 med ring: 1.2

RA-komb: 8/år som ses med båda

Detection principle



Neutrino interactions

Neutrino and gamma production in cosmic ray accelerators?

Hadronic accelerator? – cosmic ray origin?

$$pp, p\gamma \rightarrow \pi^0 \rightarrow \gamma\,\gamma$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$e^+ + \nu_e + \bar{\nu}_\mu$$

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$

$$e^- + \bar{\nu}_e + \nu_\mu$$

γ-rays from synchrotron

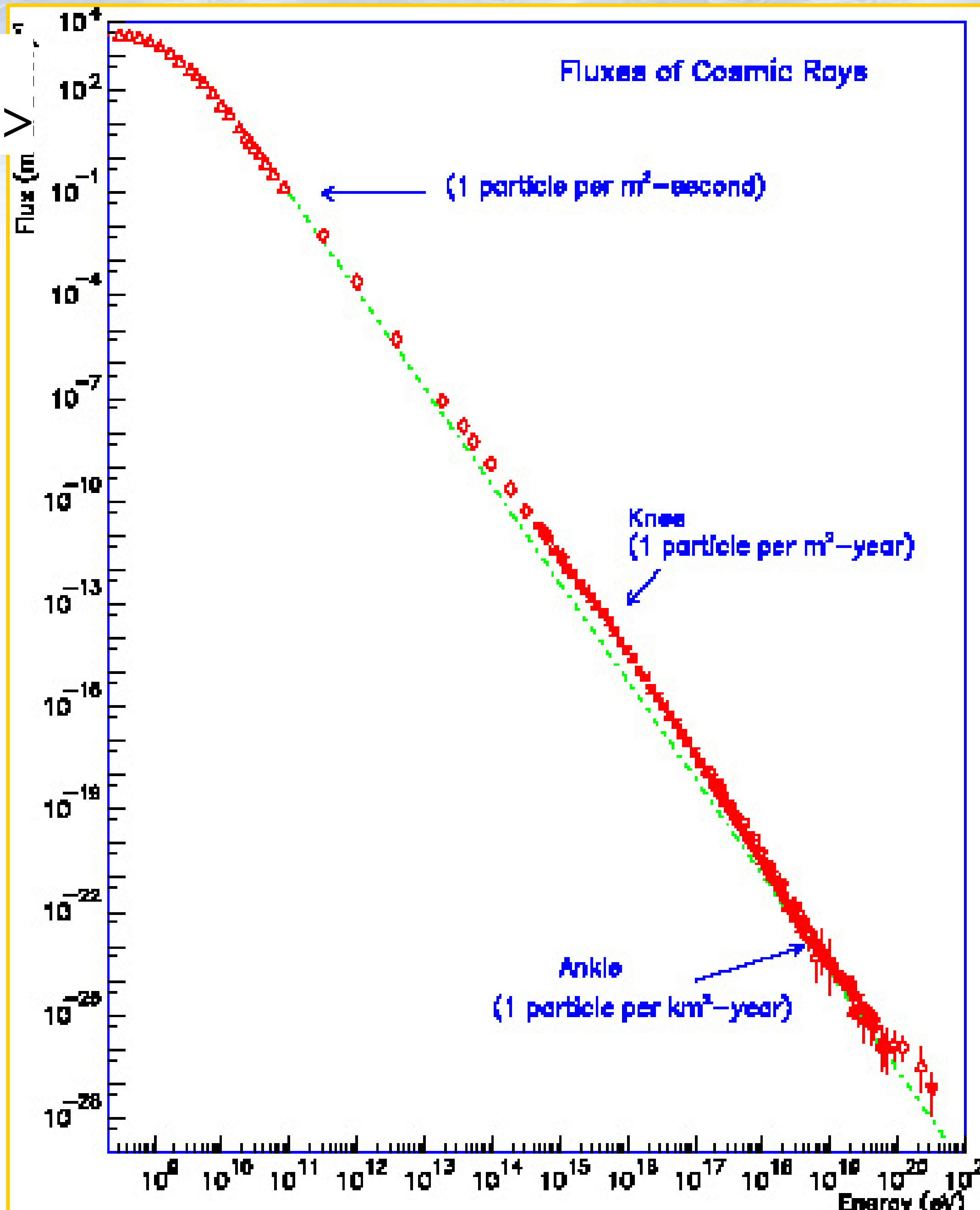
<< MOTIVATION FOR UHE SEARCHES 2 >>

Cosmic Rays

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

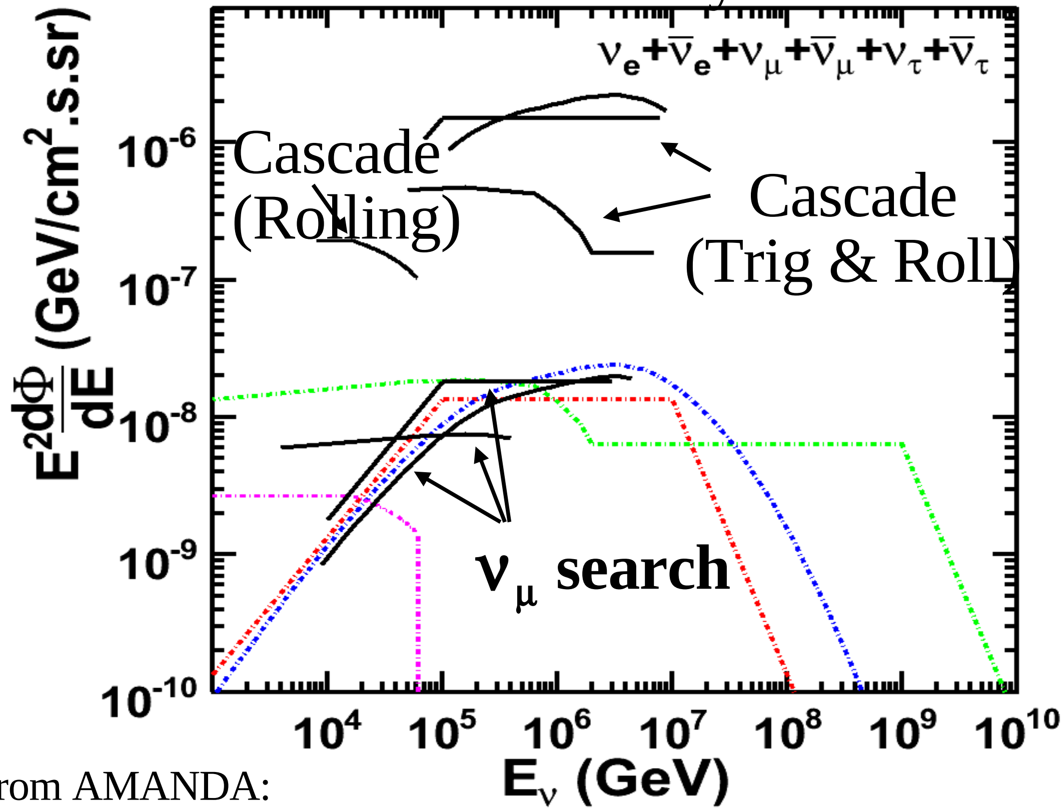
the origin of these energetic particles remains an enigma

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



Search for neutrinos from GRB

All flavor limits by AMANDA



GRB models

Waxman-Bahcall
PRL 78 (1997) 2292

Murase-Nagataki A
PRD 73 (2006) 063002

Supranova,
Razzaque et al.
PRL 90 (2003) 241103

Choked bursts
Meszaros-Waxman
PRL 87 (2001) 171102

Limits on neutrinos from GRB from AMANDA:
-from cascades (ν_e, ν_τ), Ap.J. 664 (2007) 397
-from neutrino-induced muons, Ap.J (to be published)

Historical context

Detection of atmospheric neutrinos

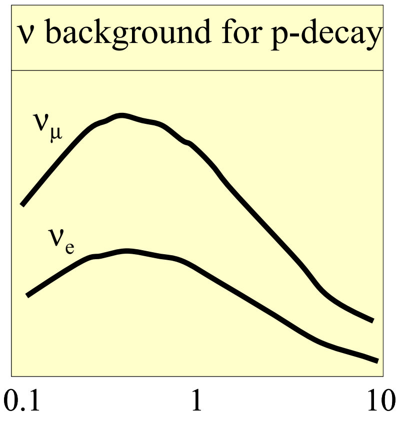
- Markov (1960) suggests Cherenkov light in deep lake or ocean to detect atmospheric ν interactions for neutrino physics
- Greisen (1960) suggests water Cherenkov detector in deep mine as a neutrino telescope for extraterrestrial neutrinos
- First recorded events in deep mines with electronic detectors, 1965: CWI detector (Reines et al.); KGF detector (Menon, Miyake et al.)

Two methods for calculating atmospheric neutrinos:

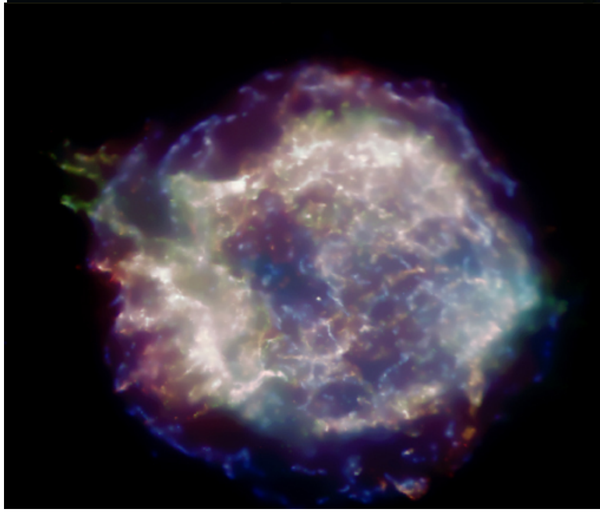
- From muons to parent pions infer neutrinos (Markov & Zheleznykh, 1961; Perkins)
- From primaries to π, K and μ to neutrinos (Cowsik, 1965 and most later calculations)
- Essential features known since 1961: Markov & Zheleznykh, Zatsepin & Kuz'min
- Monte Carlo calculations follow second method

Stability of matter: search for proton decay, 1980's

- IMB & Kamioka -- water Cherenkov detectors
- KGF, NUSEX, Frejus, Soudan -- iron tracking calorimeters
- Principal background is interactions of atmospheric neutrinos
- Need to calculate flux of atmospheric neutrinos



IceCube physics subjects

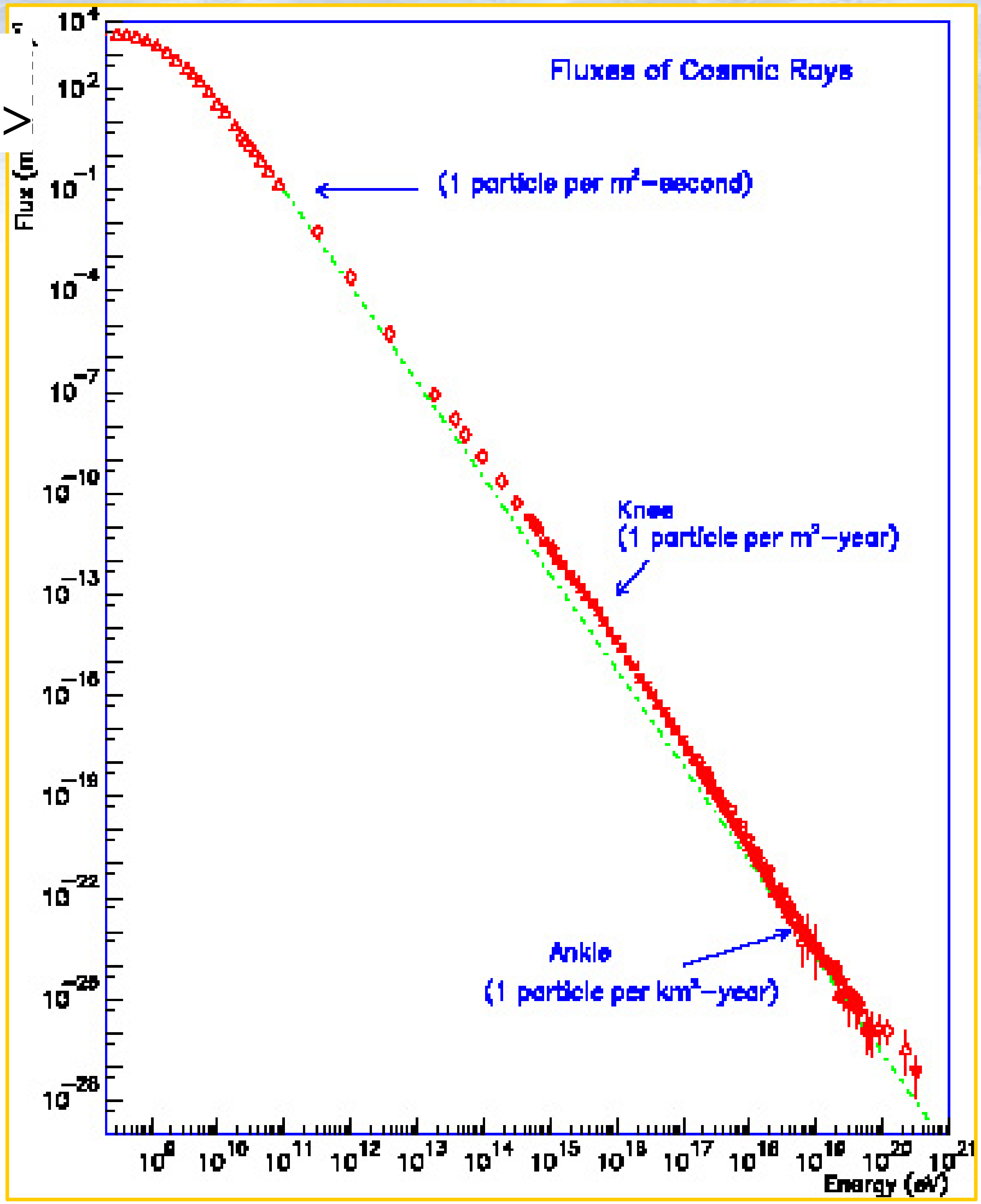


- **Cosmic accelerators**
- **Cosmic ray composition**
- What are UHE ($E \sim 10^{20}$ eV) cosmic rays ?
- Hadronic accelerators as sources of

  high energy γ ?
- “Bottom up” astrophysical sources of
- high energy ν’s ($E_\nu \sim$TeV):
  - GRB’s,
  - AGN
  - Sne

<< *MOTIVATION FOR UHE SEARCHES 2* >>

Cosmic Rays

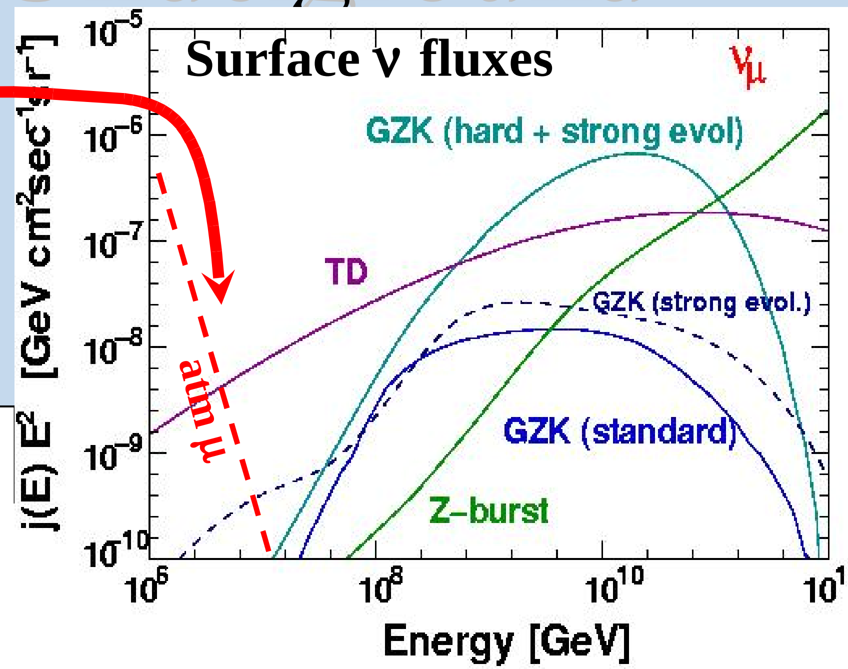


Quest for cosmogenic ν Cosmic-ray connection #3

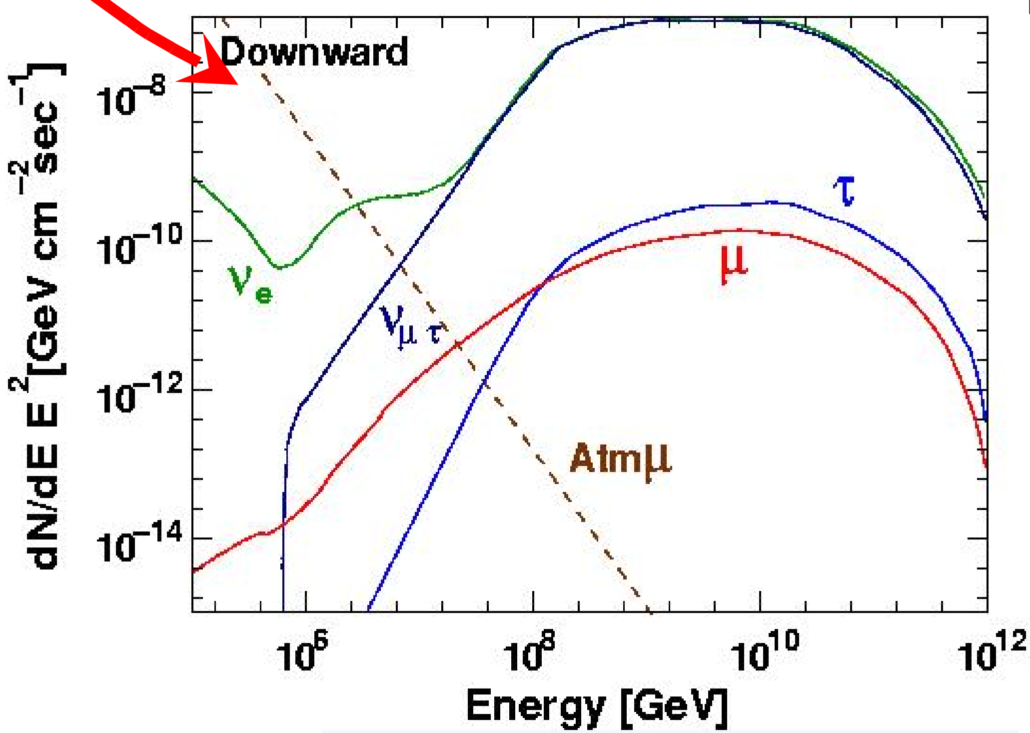
- Motivated by indication of GZK feature in UHE cosmic-ray spectrum
- Cosmogenic ν (from $p + \gamma_{2.7} \rightarrow n + \pi^{+} \rightarrow \nu$)
  - Probe evolution, composition, spectra of extra-galactic cosmic-ray sources
  - Expected rate in $km^3 \leq 1$ event / yr
  - Goal: >1000 km^3sr, > 100 events/yr, E >10^{18} eV
  - Radio detection, e.g. RICE, ANITA …
  - Acoustic detection in Ice another possibility

EHE Neutrino Underground

Target GZK neutrino
Surface energy range
8 < Log(E/GeV) < 12
(energy at depth ~ 6-7 < Log(E/GeV) < 10-11)



Fluxes at the IceCube depth

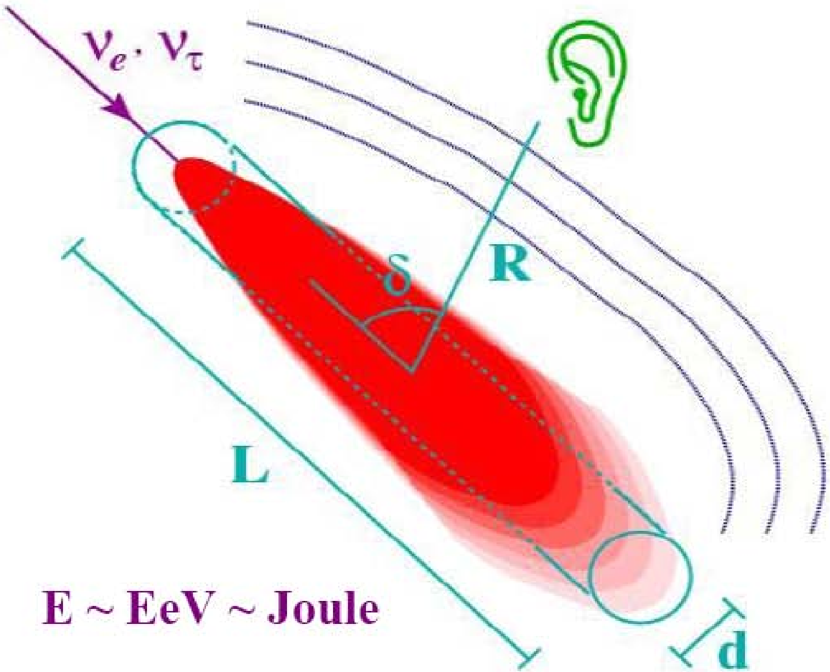


S. Yoshida et. al. (2004) Phys. Rev. D 69 103004

<u>main signal</u>
GZK neutrino induced leptons
<u>background</u>
Atmospheric muon

Si $E_{GZK} >> E_{Atm\ \mu}$

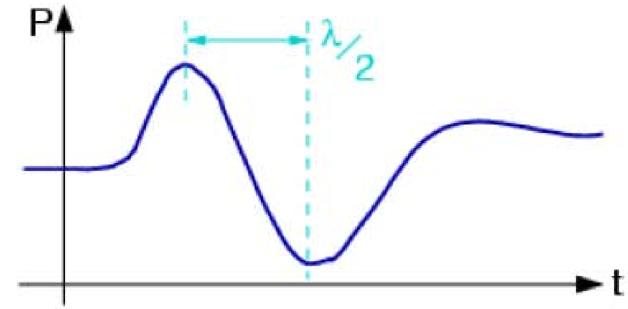
Acoustic detection



Acoustic signal:

$$P_{max} = \left(\frac{\alpha}{\mathbf{C}_p}\right)\left(\frac{\mathbf{f}^2}{2}\right) \cdot \frac{E}{R} \cdot \frac{\sin x}{x}$$

with $x = \frac{\pi \mathbf{L}}{2\mathbf{d}} \sin\delta$ and $f = \frac{\mathbf{v}_s}{2\mathbf{d}}$



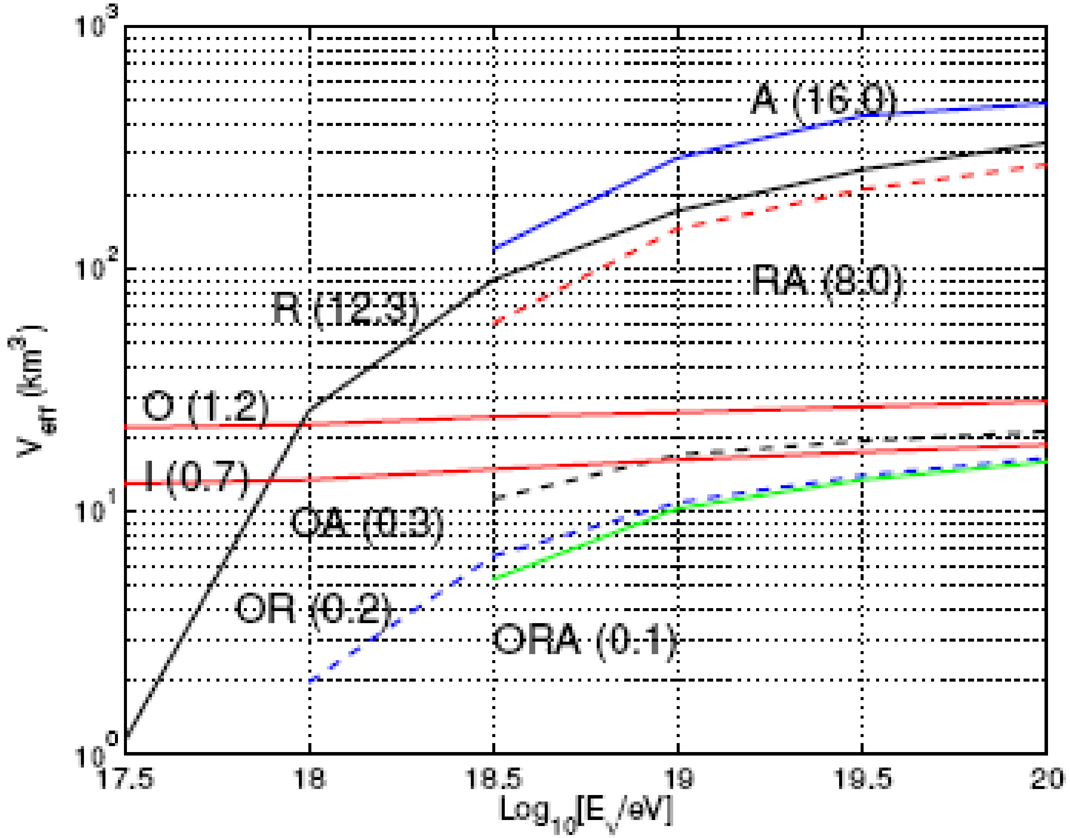
Characteristic signal:

➔ good for background suppression

Peak pressure amplitude:

		Water (20 °C)	Ice (−50 °C)
$\mathbf{P}_{\text{max}}$	$\left[\text{Pa}\,\frac{\text{E[PeV]}}{\text{R[m]}}\right]$	$0.22 \cdot 10^{-3}$	$2.2 \cdot 10^{-3}$

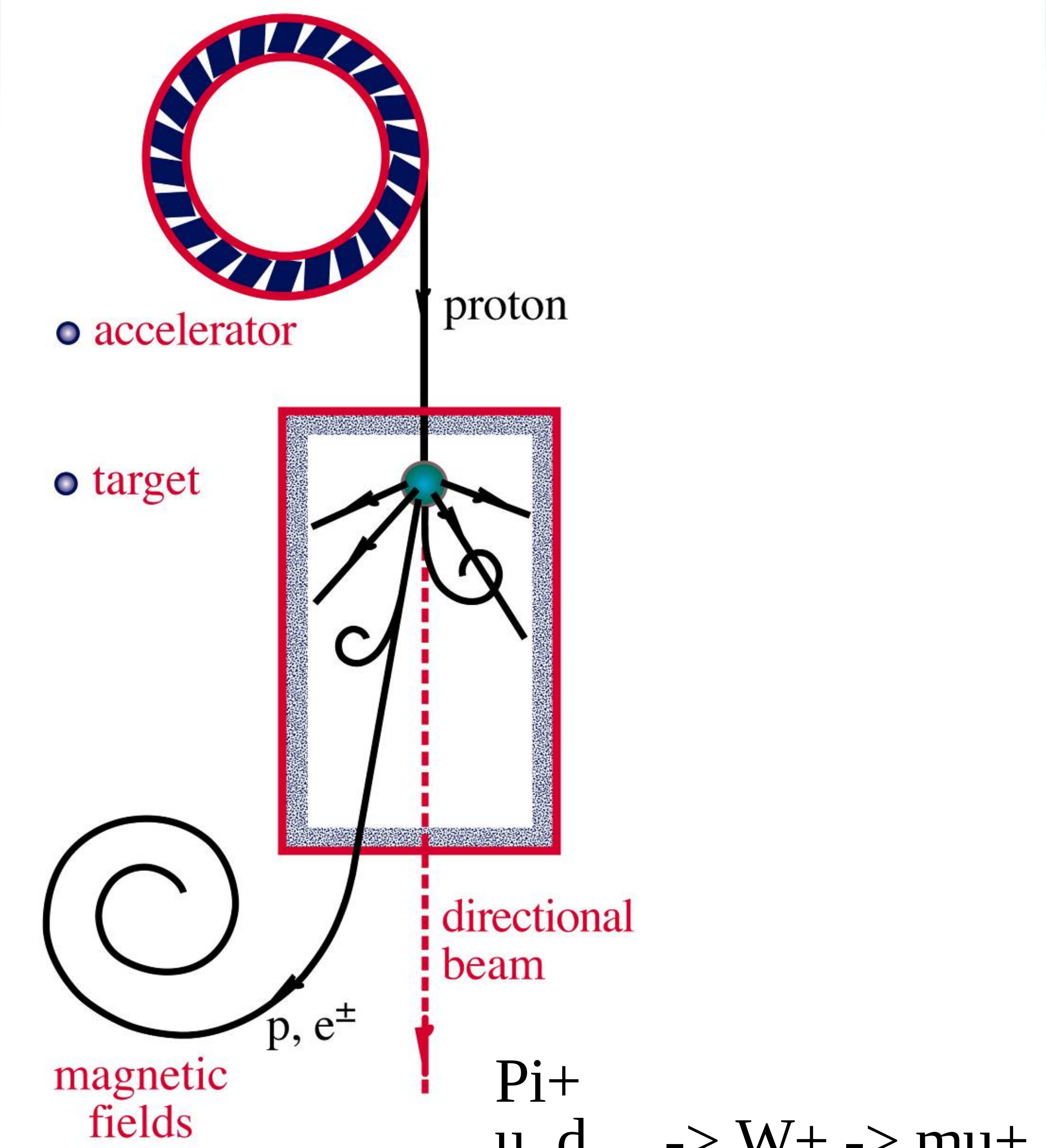
Monte Carlo Simulated Combined Array

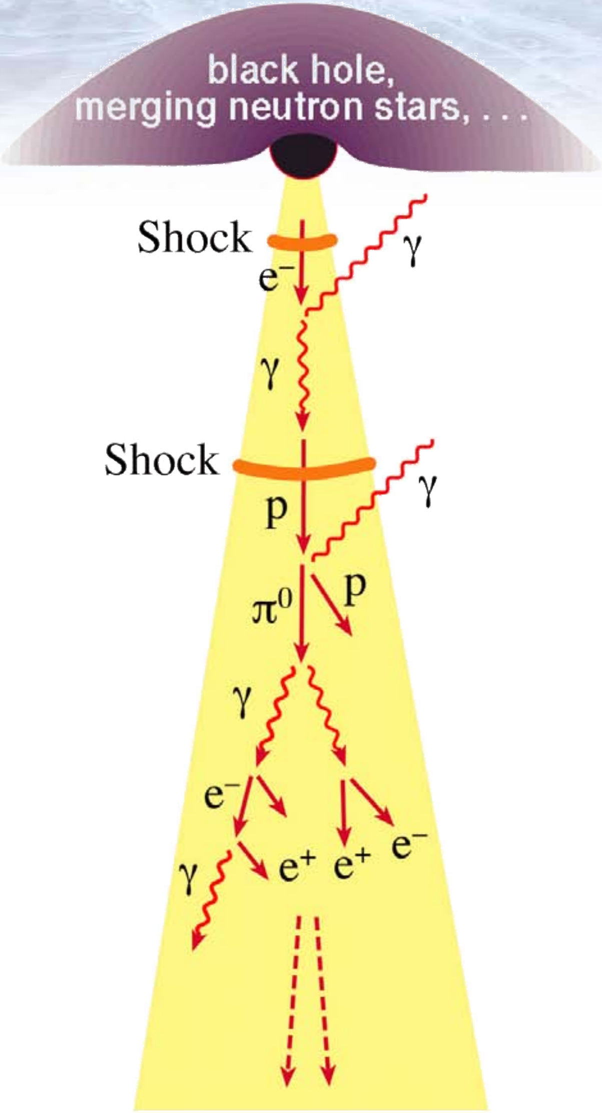


Detected GZK-neutrinos/year

Combination of methods is powerful

Neutrinos as messengers

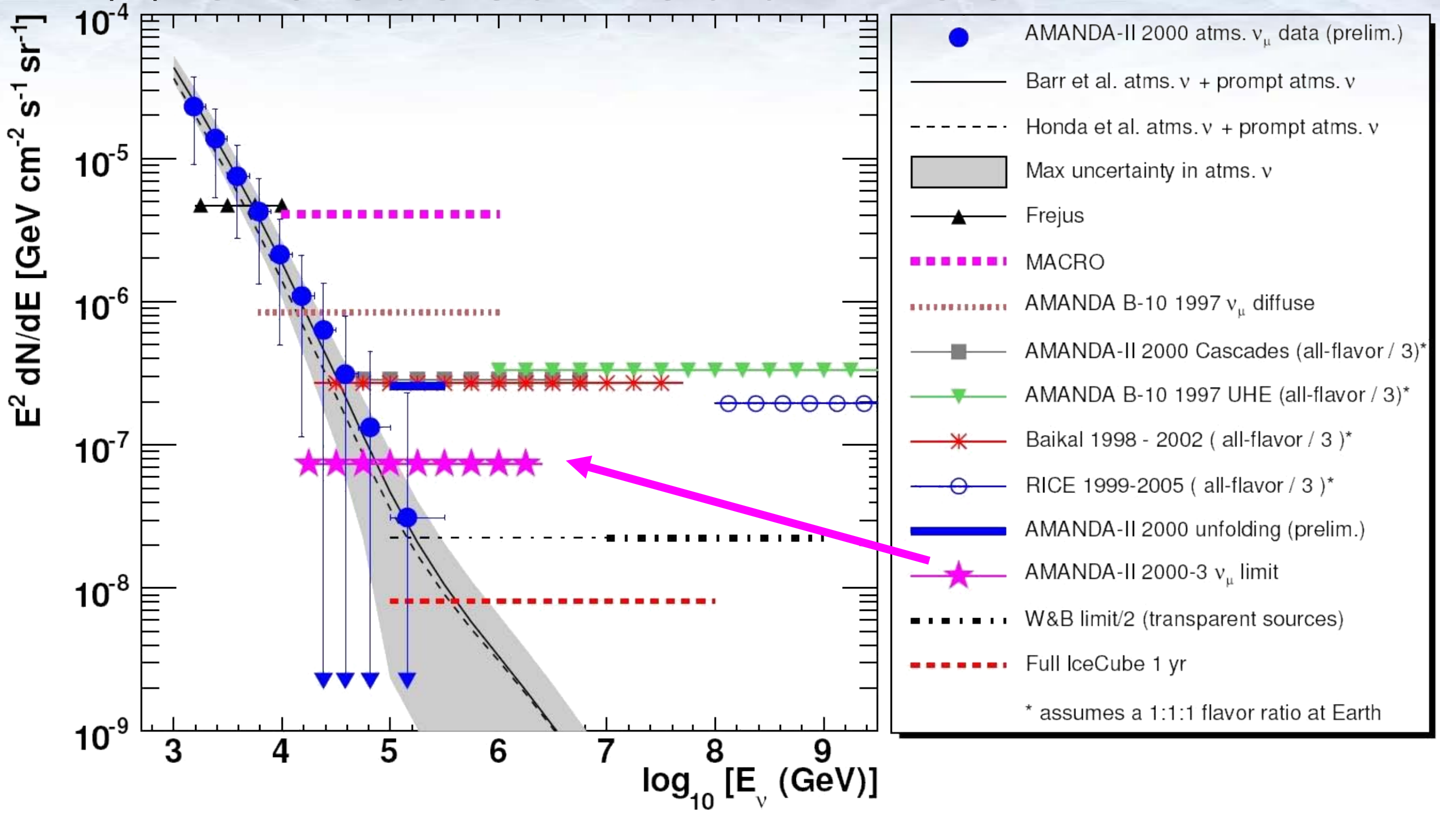




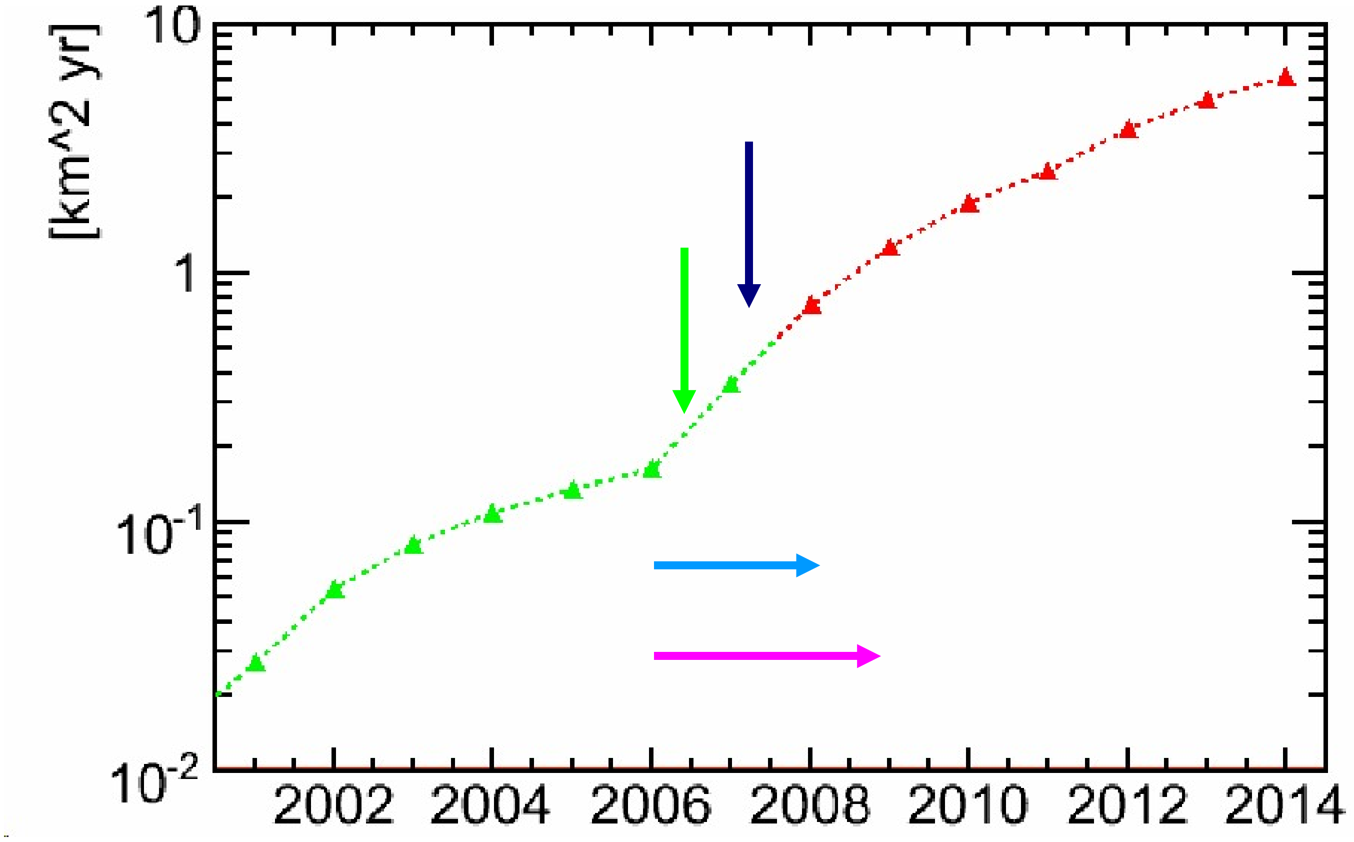
Pi+

u, d_ -> W+ -> mu+ , numu

We detect neutrinos

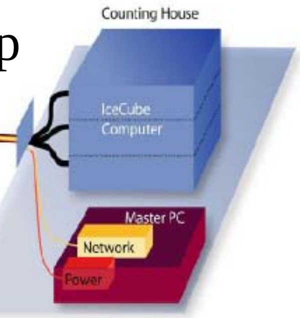
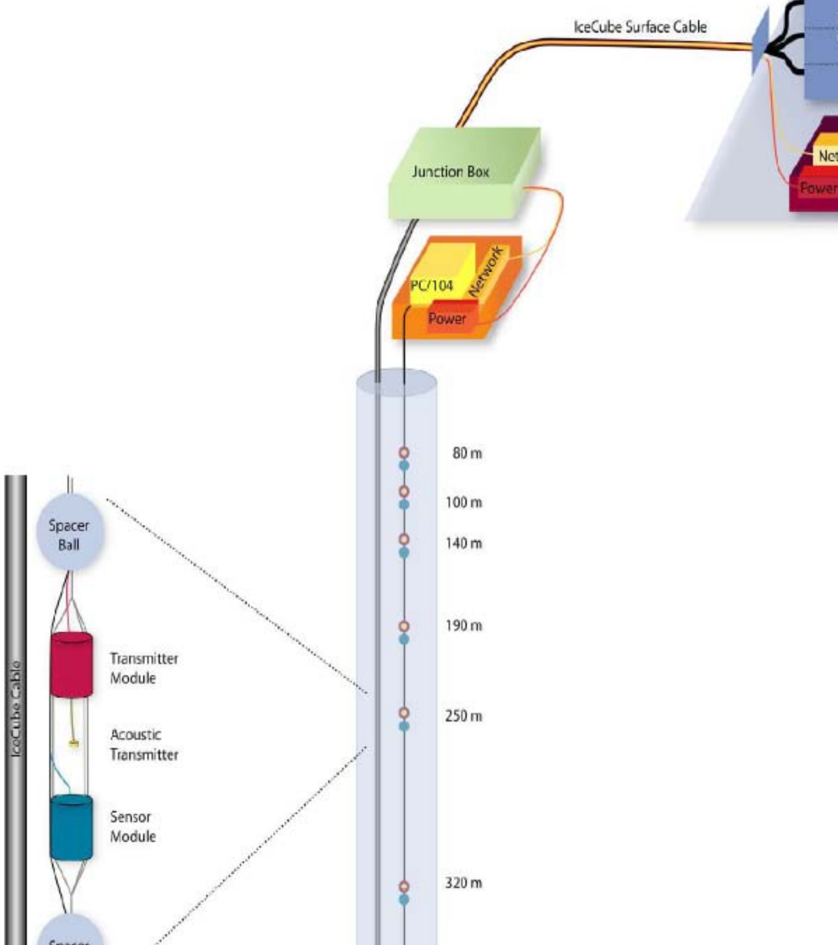


IceCube accumulated exposure at 100 TeV

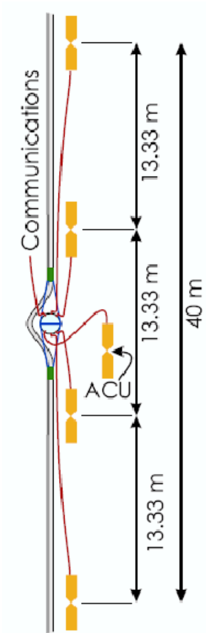


Future extensions

South Pole Acoustic Test Setup

AURA Digital Radio Module



Possible hybrid array